PHOTOGRAPHY IN COLOURS

G. L. JOHNSON

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So very, very
true, and so
very, very
pretty.
Just as
pictured.

PLATE I.

PHOTO BY VIVIAN P. DAVIS.

JULY AT HAMPTON COURT.

Reproduced from a Raydex photograph.

Frontispiece.]

PHOTOGRAPHY IN COLOURS

BY

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IN PHOTOGRAPHY AND THEORETICAL AND APPLIED OPTICS TO THE SPECTACLE
MAKERS' COMPANY, LONDON; ETC., ETC.

WITH FOURTEEN FULL-PAGE PLATES (FIVE IN COLOUR)
AND NUMEROUS ILLUSTRATIONS IN THE TEXT

NEW AND REVISED EDITION

NEW YORK
E. P. DUTTON AND COMPANY
1917

PRINTED IN GREAT BRITAIN

PREFACE

TO THE THIRD EDITION

The writer has not found it necessary to make many alterations in this edition. In fact he has only corrected a few errors in the text, and rewritten page 91 (§ 43) which answers the question "How the appearance of White is produced on a Colour plate." He regrets that he did not give sufficient credit to Professor Forster for his interesting discovery of the reason why white can be photographed as white on a colour plate, and he has, therefore, rewritten the paragraph relating to it.

But if few alterations have been found necessary, he has been obliged to enlarge the book somewhat, owing to the progress which has been made since the last edition was written. A full description of the Raydex process has been added, as well as Gaumont's new method of Cinematography in Colours, and Carrara's method of reproducing Autochromes on paper.

A chapter has been added on Art in Colour Photography, and also a further chapter on Photomicrography in Colour. The writer desires to express his sincere thanks to Mr. Walter Severn, A.R.C.Sc., F.C.S., for revising the latter. His great experience in this department of microphotography as Assistant Government Bacteriologist in Cape Town is a guarantee of its accuracy. He desires to add that the apparatus arranged for taking microphotographs by combining a vertical microscope with a horizontal camera is entirely Mr. Severn's own invention, as are the special methods of staining the slides.

Castle Mansions,
Johannesburg, 1916.

PREFACE

TO THE FIRST EDITION

Since the publication of my previous work, "Photographic Optics and Colour Photography," the advances made in Photography in Colours have been so great that, rather than revise the former section on Colour, it was thought desirable to write an entirely new work on the subject, which should embody all the latest methods. This I have endeavoured to do, and it is hoped that the Amateur will find all the information he requires in this work to practise any of the recognised colour methods with success. There is a general impression among Amateurs that both single-plate and three-plate colour photography present great difficulties to the beginner, but I can assure the reader that it is not the case. Single-plate colour processes at any rate are quite as easy to manipulate as ordinary dry-plates, and occupy even less time than the latter.

The striking analogy which exists between the physiological perception of colours and the phenomena associated with colour photography has convinced me that both the ophthalmic surgeon and the physiologist who have taken up the study of colour blindness and colour vision, will find that the serious study of this fascinating science will illuminate many obscure phenomena connected with the physiology of vision and colour blindness, and will well repay them for the time spent in acquiring a practical knowledge of at least one of the leading processes described herein.

I beg to offer my thanks to those who have assisted me in revising the work, and also to the makers of the "Autochrome," the "Dioptichrome," the "Omnicolore," and the "Thames" colour plates, for revising the sections devoted to their processes, as well as for a large number of practical hints scattered throughout the work.

Lastly, my best thanks are due to Dr. Kenneth Mees for elucidating several points of difficulty, as well as to the Editors of the *British Journal of Photography* for the loan of the Photomicrographs of the various "colour-screens."

G. LINDSAY JOHNSON.

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CHAPTER I

THE NATURE OF LIGHT AND COLOUR

§ 1. **Sources of Light.**—When a body is raised to a high temperature it becomes incandescent, and sets up vibrations or waves in all directions in the ether, which waves, impinging on the back of our eyes, give rise to the sensation of light. With the exception of Fluorescence, Phosphorescence, and a few other sources of energy, which need not concern us here, all light has its source in bodies which are in a condition of white heat or incandescence. Thus we see either by reason of the white hot matter of the sun and stars, or by means of artificial sources, such as the incandescent particles of carbon in a candle or gas-flame, or the white-hot filaments in the electric bulb. It is by no means necessary that the source of light should be seen. Thus most of the objects around us, such as the moon, trees, houses, etc., are rendered visible by the light reflected from them, which light can invariably be traced to one of the sources just named.

§ 2. **Nature of Light.**—The way in which objects are seen, and what constitutes light, are problems that have occupied the mind of man ever since he became

a thinking animal. The primeval savage must have observed that the gilding of the sky, and the creeping darkness, accompanied the setting sun. He must have wondered why his spear appeared bent when he thrust it into the pool, and why his shadow became shorter as the sun rose in the heavens.

The Greeks, who wasted far too much of their time in fruitless speculation without testing their theories by experiment, imagined that light was something that passed from the eye to the object seen, in the form of some invisible tentacle or emanation. This theory was abandoned for the one that sight was due to the impact of an infinite number of minute luminous corpuscles which stream out from every visible object at an immense velocity, entering the eye and giving rise to vision by their impact against the retina, much in the same way that the particles or corpuscles are seen to dart out of a speck of Radium when observed through a Spinthariscope. The fact that light could pass through glass and other transparent bodies, was accounted for by the supposition that these corpuscles were so minute that they could pass between the molecules of any transparent substance. This view, which is known as the Corpuscular Theory, was held by Newton; but Huyghens, his contemporary, was the first to propound the wave theory of light. Unfortunately the wave theory was overshadowed by the great name of Newton, and it was not generally accepted until the experiments of Thomas Young and Fresnel established it on a solid basis at the beginning of the nineteenth century.

In order to understand the wave theory, we are

obliged to assume the existence of an omnipresent medium which is called the Ether.

§ 2A. **Ether.**—This is supposed to be a perfectly elastic, frictionless, and imponderable medium which occupies the entire space throughout the visible universe, surrounding and penetrating the molecules and atoms of which all matter is composed. It is further supposed to be absolutely motionless, and also to possess enormous rigidity, so that no amount of force is able to rend or displace it. Its chief property is that of propagating vibrations or waves which travel transversely to the line of force. These waves radiate in every direction like the circumference of an ever-expanding globe when considered as a whole, although any single wave propagated from the source of origin will continue to generate waves in a straight line to an infinite distance without any appreciable loss of energy. It is further supposed that gravity, or the action of one body on another at a distance, together with the various forms of energy, such as light, radiant heat, electricity, magnetism, Hertzian waves, etc., are all manifestations of the same wave motion, and that these waves are due to stresses in the ether, which are propagated through that medium with immense velocity. These light waves are supposed to cause movements in the ether, which are so small and so rapid that the latter behaves like an elastic solid. The familiar illustration of waves formed in a still pond may help the reader to grasp the idea. If the surface of a smooth pond be strewn with corks, and a stone be thrown into it, a series of concentric circular waves will be generated which will spread further and further to the shore, but

the water itself will not travel, as will be shown by the corks, which, although they bob up and down, nevertheless remain where they were originally placed. In like manner the ether remains unmoved, save that minute stresses are caused which propagate impulses with the velocity of light in all directions, and which follow one another with inconceivable rapidity, the frequency amounting to many billions of waves per second.

§ 3. **Nature of Ether Waves.**—The energy engendered by the source of light sets up vibrations transversely to the direction of motion. These waves vary enormously in length, *i.e.* in the distance between the crests of successive waves. Thus many kinds of electrical vibrations, especially Hertzian waves, vary from two or three mm. to several miles in length, whereas the waves which we perceive with our eyes vary between 768 $\mu\mu$ (millionths of a mm.) for the dark red rays, to 375 $\mu\mu$ (or slightly less than half the former length) for the violet rays. By passing the light through a fluor spar prism, waves of only 200 $\mu\mu$ can be rendered visible, and by the additional help of photography and the use of a vacuum camera, waves of a still shorter length, viz. 100 $\mu\mu$, can be registered on the photographic plate. Waves which exceed 768 $\mu\mu$ in length are invisible to the unaided eye, and are called the *infra-red* or heat-rays of the spectum. These, although they cannot be seen by the eye, may be regarded by means of an instrument called a Bolometer. Those rays which are shorter than 375 $\mu\mu$ belong to the *ultra-violet* end of the spectrum, and are likewise invisible.

§ 4. **Brief Outline of the Wave Theory.**—Every part of a source of light generates a wave, which travels in every direction. Let one of these parts L be an incandescent point of light. This will form the centre of a minute sphere whose diameter is equal to a wave length (λ). Every point in the circumference of this sphere will at once form a fresh centre of disturbance and will generate a new sphere, and this again another, and so on. Now every one of these tiny spheres may be supposed to lie side by side, each overlapping its fellow, forming tangents to points on their combined circumference, which points are situated on imaginary radii from the original point of light.

Since each fresh sphere generated from the smaller sphere behind it, has for its centre a point on the same radius, tangents to points on their combined circumference will, if taken collectively, form a wave front (*a*, *b*, *c*, *d*, *e*). Now, as the centre of each sphere lies on the wave front of the sphere behind it, the diameter of each sphere is clearly equal to a wave-length. Each successive wave front (λ_1, λ_2) (Fig. 1) may thus be considered

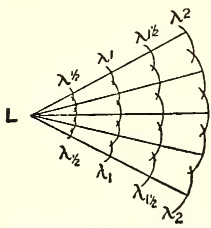


FIG. 1.

as the crest of a wave, and the space between it and the next wave front ($\lambda_{\frac{1}{2}}$, $\lambda_{1\frac{1}{2}}$) as the trough of a wave. Thus light waves advance to form an ever enlarging sphere, and the tangent to this sphere represents the wave front. Since the centre of each tiny sphere lies on a common radius, light waves may be said to advance in straight lines from the source, just as waves

may be said to travel along a stretched rope when it is shaken. Such a straight line of force is termed a *ray*. A small collection of such rays is termed a *pencil*, and a larger one a *bundle*, or if divergent from a point of light a *cone* of rays. For some purposes it will be found more convenient to refer to light in terms of its wave front, but for most purposes, and more especially in geometrical optics, the direction, and not the wave front, has to be considered, and may conveniently be represented by a straight line.

We must also distinguish between a train of waves and a single wave. If we take the familiar example of the stone dropped into the pond, we notice that the front wave gets feebler and feebler as it spreads out towards the shore, while the main body or train of the waves moves on undiminished. In free ether, as there is no resistance, both the train and the single waves travel unimpaired to infinity, but in a refracting medium such as glass or water, the single waves become rapidly exhausted. Thus a single wave cannot pass through a thin microscope cover-slip, much less through a plate of glass. It has been found that in Bisulphide of Carbon a wave loses $\frac{1}{14}$ of its amplitude for each wave-length, and that after 14 or 15 wave-lengths the wave has quite died out. The train also suffers in a dense medium, not only by becoming slower in direct proportion to its refractive index, but by becoming exhausted as well. The train of waves lose about $\frac{1}{50}$ of their amplitude for each fathom of water penetrated, so that light cannot pass through a thickness of 50 or 60 fathoms. Objects below that depth being in absolute darkness. Of course a much

less thickness of glass would suffice to obstruct all light. The difference between trains of waves and single waves may be illustrated by a regiment of soldiers who are taking a fortress by assault. The front men drop down one by one, but the main body of men, which represents the train of waves, rushes on unhampered to the goal.

§ 5. **Electro-magnetic Theory of Light.**—Although it is generally accepted that light is due to transverse vibrations set up in the ether, it is extremely doubtful if these vibrations are propagated by successive portions of the ether which set each other in motion, since this force can be resolved into two components, one of which will be found to be in the direction of the wave-front, and will consequently set up longitudinal vibrations. But there is no evidence whatever to prove that longitudinal waves can be transmitted in ether at all.

Clerk Maxwell, in his electro-magnetic theory of light, got over this theory by supposing that the waves do not necessitate any change in the position of the ether particles, but that they cause periodic and almost instantaneous changes in their electro-magnetic condition. Faraday showed that the ether was a perfect dielectric (non-conductor) which, like all dielectrics, is capable of polarisation. He traced all electric, magnetic, and optical phenomena to stresses in the ether. In fact we can classify these ether stresses according to the size of the waves and their method of formation, so that we are able to group them into light waves, heat waves, and electric waves. By means of the electro-magnetic theory Clerk Maxwell

established the close relationship between light and electricity on a mathematical basis, and it remained for Hertz, the brilliant pupil of Helmholtz, to prove experimentally that electric waves were not only propagated in straight lines, but were capable of reflection, refraction, and polarisation. Further, the velocity of electric waves was measured and found to be identical with that of light. In a word Hertz demonstrated by experiment the truth of Clerk Maxwell's assumption, that light was nothing more nor less than an electro-magnetic effect in the dielectric and polarisable ether. Whenever electric waves pass through a dielectric we get a displacement at right angles to the direction of the wave, exactly as we find to be the case with light-waves in the ether.

The phenomena of electrolysis, kathode rays, Becquerel rays, and especially the Zeeman and the Kerr phenomena, all go to prove that electricity is merely another condition of light; and physicists seem to be more or less agreed that the electrical phenomena are due to the propulsion of electrons, which are the smallest particle of any body we know of, and which appear to be a kind of transition between matter and ether. Whenever an electron is set free, it is accompanied by an electric current which sets up a stress in the ether, and generates a series of intensely rapid alternating positive and negative electric polarisations or displacements whereby the electro-magnetic waves which exhibit the phenomena of light are produced.

The reader must dismiss the popular idea that electricity is a fluid which passes through, or is dis-

tributed around, a conductor or wire. Electricity (or light) charges the surrounding ether with energy which manifests itself in the form of waves. Whenever an electric conductor is said to be charged, *it is not the conductor or wire which is charged, but the ether around it,* and a flow of electricity merely implies a flow or distribution of energy through the electric or electromagnetic field.

§ 6. **The Nature of White Light.**—The classical experiments of Newton apparently showed that white light consisted of a mixture of all the colours, and that a prism merely separates them out into the seven primaries. We find this stated as a fact in the majority of text-books even to-day. If, however, we examine the question a little more closely, we find the solution is by no means so simple. It is evident that white light consists of an infinite number of trains of waves each having a different wave-length. Hence the stresses set up in the ether must be the resultant of all these numberless trains, and consequently they can have no regularity of sequence. On the other hand, we know that a prism or grating will separate white light into a number of distinct colours, and a pure colour can only be produced by a regularity in the sequence of the train waves. Hence arises the question, does the prism or grating separate out the waves into orderly trains of sequence, or were they originally present in the white light? As Professor Wood rightly puts it, if the regular wave trains were manufactured by the prism, was Newton's discovery really a discovery after all?

The answer to this question is an extremely

complicated one, and it is very difficult in an elementary text-book to make the reasoning intelligible to the ordinary non-mathematical reader. Many Physicists insist that white light from a source consists of regular trains of waves, because interference fringes can be obtained from it, either by employing two slits, or by means of Fresnel's mirrors (*i.e.* by reflection from two mirrors placed at an extremely wide angle to one another). But Schuster has shown that the interference is due to a physiological peculiarity of the eye. We may consider that all the retinal rods and cones are toned to the three primary colours in the same way that musical instruments or gas flames enclosed in glass tubes respond to certain vibrations or multiples of them. This conception is quite a different thing from Helmholtz's idea that the cones were divided into three groups, each one responding to one of the three primary colours, and not to the other two. According to Schuster's theory, the retinal elements have a period of their own, so that they respond to certain wave-lengths and not to others. Now suppose the white light to consist of a series of pulses which result from an immense number of simple harmonic waves differing from one another by insensible gradations. When two pulses strike a cone one after the other the effect will depend on the interval between the two impacts. If the first impact sets the cone vibrating and the second shock arrives before the first has died out, interference will obviously take place, the second impact either intensifying or annulling the first one, according to whether the waves are in the same phase or a different one. In this way interference fringes can

readily be seen. The molecules in minute particles of silver compounds in the film likewise have their periods of resonance and can be set vibrating, and Schuster has even succeeded in photographing the fringes formed.

We may perhaps explain the whole matter in a very simple way :—Imagine a post bag filled with letters from London and forwarded to Liverpool. The letters are all mixed up anyhow. This represents our waves of white light. On arriving at the G.P.O. in Liverpool some are sorted for the United States, some for local distribution, some for the Docks, and so on. This sorting corresponds to the effect of a prism or grating which manufactures the colours by sorting out the wave-lengths into regular periods corresponding to their respective wave-lengths. But suppose that the United States letters were held back at the post-office, and then added to others going in the same direction so that they could all arrive at New York in a number of big sacks. This would represent the way in which the pulses follow on in the eye by the fusion of the periods of resonance due to the first pulse with that of the next arrival.

§ 7. **The Cause of the Sensation of Colour.**—The proof that colour is due to the frequency of the vibrations, and not to their wave-lengths, can readily be shown by their analogy to sound waves. Our sensations of light and colour are due to an enormously rapid succession of waves, or taps, on the ends of the rods and cones of the retina, which we can perceive provided their frequencies lie between certain limits. Exactly the same thing happens to the ear in the case of sound

waves. These latter vibrations are termed the pitch of the note, and we can hear them, provided they amount to not less than 39 or more than 36,000 vibrations à second, when they tap the hair cells of our auditory nerve, which is situated inside the inner ear. Now, owing to the slow rate of our auditory vibrations, it is quite easy to show that the pitch or musical colour is determined by the frequency of its vibrations, and not by the note, or musical wave-lengths. From this we may infer that colour is due to the frequency of the waves and not to their wave-length.

Again, we know that the velocity of light is retarded when passing from air through a denser medium such as water or glass. If, therefore, we allow a colour of known wave-length, such as sodium light, to pass through the slit of the spectroscope, and place in its path a plate of glass, it should cause an alteration in the colour towards the blue end of the spectrum, owing to the reduction of the speed. But no such change can be observed. Hence, in the equation $V = \lambda f$, where V = velocity of light, λ = wave-length, and f = frequency, if we reduce V in causing the light to pass through the glass plate, we must either reduce λ or f to satisfy the equation. But, as we have just seen, colour does not change when light passes through a denser medium, therefore colour must be due to frequency and not to wave-length.

§ 8. **How Colour is Produced.**—The chief source of colour in objects is selective absorption of portions of the constituents of white light reaching it, and the scattering of the residue, which latter causes the colour of the objects which we perceive.

In the same way, when white light passes through any substance some of its components are absorbed, while the rest of the light which emerges is coloured in consequence. An object is only colourless when white light passes through it unchanged, the portion absorbed consisting of trains of waves of every refrangibility.

When light reaches the surface of any non-transparent object, it either penetrates a greater or less distance beneath the surface, where it is reflected and scattered by the layers and the surface, and thus reaches the eye; or it rebounds directly from the surface from whence the light is scattered by its inequalities. In the latter case the light remains unchanged, but in the former case some of the constituents of the light are absorbed, the remainder being coloured light which gives the characteristic hue or colour to the substance. For example, a rose appears red because the white light falling on it penetrates the cells of the petals which absorb the green and some of the blue constituents of the light, while all the red, some of the blue, and some of the unchanged light is reflected back and scattered at, or beneath, the surface, giving the impression to the eye of a pink or red flower. It is because substances with few exceptions are not homogeneous (that is of uniform density throughout) that internal reflections and refractions occur which project the unabsorbed light into space, and thus give rise to colours. To this action, according to T. E. Goodall, the luminous shadows which appear on the human face are due. When a faint shadow is thrown upon the face, a portion of the

light penetrates the skin and is reflected back by the reddish tinge of the layers beneath. It is to this that the warmth of tone and transparency of the shadows are due. In the portraits by the old masters the painter seized upon this effect which gave such life to the portraits. To those who use face powders this reflective action of the skin is prevented, hence the corpse-like shadows which are seen instead of the beautiful pearly luminosity of a fresh untouched face.

To say, as some text-books do, that bodies and pigment particles reflect certain colours more strongly than others is incorrect. Light reflected from a homogeneous medium is always white.

The difference between a liquid and its froth is a striking example of internal reflections and scattering of the light. Thus, a block of ice has a pale cobalt-blue colour, but when powdered it is quite white. In the same way the crest of a wave blown about by the wind, or the froth of beer is white. Almost any crystalline substance, whatever its colour, will become white, or nearly white, if sufficiently finely powdered, or condensed in the form of snow. This can be readily shown in the case of sulphate of copper, or bichromate of potassium crystals. In all the above cases the light which falls on the liquid or powders suffers reflection or refraction at the surface of each particle or bubble on which it falls. These rays undergo innumerable reflections, and the light is scattered in every direction. As very little light is absorbed all the colours are equally reflected, and at the same time the intensity of the intromitted rays is almost unimpaired; the result being that the surface of the body appears dazzling

white. Thus a cloud when at a great elevation consists of minute crystalline ice-particles (cirrhus clouds) which particles are so small in comparison with their areas, that gravity has little or no effect on them, and they form brilliant white clouds. If the pressure of the atmosphere diminishes the clouds sink, and the particles melt and run together. This causes the light to become more absorbed, and they form cumuli. But since the light is not selectively absorbed they appear grey. If the clouds condense still more, the light is largely absorbed, and they form dark nimbi or rain clouds.

If in the case of bodies or liquids the substance has a selective power of absorption, the emittent rays are deprived of some of their constituents, and the body appears coloured. In some cases—as, for instance, the powders above mentioned—the light is reflected very close to the surface, and does not pass through enough of the substance to allow of any selective absorption.

§ 9. Coefficient of Absorption and Transmission of Light.

Lambert's Law.—Lambert found that the amount of light which passed through a coloured filter or glass plate diminished in geometrical progression as the thickness increased in arithmetical progression.

Thus, if we superpose a number of layers of, say, one millimetre thick, as the thickness of the layers increases in the ratio of 1, 2, 3, 4, 5, etc., the intensity of the emergent light will diminish in the ratio of 1, $\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{8}$, $\frac{1}{16}$, etc., so that if we place a series of identical coloured glasses of the same thickness one after another

in front of the lens in a camera, the exposure would be in the ratio of 1, 2, 4, 8, 16 times, as the thickness traversed by the light was increased from 1 mm. to 2, 3, 4, and 5 mm.; or, to put it in another way, the exposure varies as the logarithm of the thickness. Thus, let I = intensity of the incident light, and Ia = intensity after transmission, through a unit of thickness, (t) being the coefficient of transmission. Then for one unit of thickness (or t) we have an intensity $= \mathrm{I}a$, for $2t$ an intensity $\mathrm{I}a \,.\, a = \mathrm{I}a^2$, for $3t$ $\mathrm{I}a \,.\, a \,.\, a = \mathrm{I}a^3$ . . . and for xt an intensity of $\mathrm{I}a^x$.

As a rule, the colour merely increases in depth with the thickness of the material, but there are exceptions to this. For example, the well-known liqueur Crême de Menthe, which is sold in Florence flask-shaped bottles, when held up in front of a small source of light, such as an incandescent globe, appears green in the neck, but red in the spherical part, and a yellow transition at one spot between the two. The explanation of this is as follows:—Let I_g, I_r be the initial intensities for the green and red colours, and a_g, a_r their coefficients of transmission. Then, from what we have just stated, the intensities of the colours after transmission will be $\mathrm{I}_g a_g^x$ and $\mathrm{I}_r a_r^x$. Now, if the thickness of the plate is small, there will not be much difference between a_g and a_r, and if I_g is much greater than I_r, and a_r only slightly greater than a_g, then I_g (that is, the green rays) will greatly predominate, and the liquid will appear green. If we increase the thickness of the layer it is obvious that a_r will greatly exceed a_g until $\mathrm{I}_g a_g^x = \mathrm{I}_r a_r^x$, when the two intensities coincide, and the result will be yellow. Thus, suppose $\mathrm{I}_g = 100$,

$I_r = 50$, $a_g = 5$ and $a_r = 8$, then, since $I_g a_g^x = I_r a_r^x$, by changing it into logarithms we may write

$$x = \frac{\log I_g - \log I_r}{\log a_r - \log a_g}$$

or

$$\frac{\log 100 - \log 50}{\log 8 - \log 5} = \frac{2 - 1{,}7}{0{,}9 - 0{,}7} = \frac{0{,}3}{0{,}2}$$

Therefore $x = 1$, thus determining the thickness at which the two intensities are equal and the liquid appears yellow. If the thickness be still further increased, $I_r a_r^x$ will be greater than $I_g a_g^x$, and the liquid will appear red when held up to the light.

A still better example of di-chromatism can be made by dissolving "Brilliant Green" and Naphthaline Yellow in hot Canada Balsam, and, when cool, squeezing the mixture between two glass plates ground in the form of a thin prism. The thin end of the wedge will then appear green, and the thick edge red, and somewhere between the two ends where the transmission is the same for both, yellow.

When a white flower is placed in coloured light, it assumes the colour of the light thrown on it, since it does not absorb any special colour, but reflects all light equally. In the same way most coloured flowers will assume the colour of the light in which they are placed, but some flowers absorb so much of the incident light that they appear nearly or quite black. Thus a red poppy or a red tulip will appear a brilliant red in red light, but nearly black in green or blue light, since the cells of the petals are filled with a substance which absorbs the green and blue light. On the other hand, a red rose or a carnation will appear a brilliant blue in

blue or greenish-blue light, or if seen through spectrum-blue glasses, but appears unaltered in a red or white light.

If a dilute coloured fluid be placed in a white basin, the white light which penetrates the fluid will be reflected from the interior of the basin, and after being deprived of certain constituents will appear of its proper colour to the eye. If the same fluid be placed in a black basin all the light will be absorbed, and the liquid will appear black. If, however, some white powder be sprinkled into the basin, the white particles will reflect and scatter the light so that the original colour is restored to the liquid.

The colour of pigments is entirely due to their power of absorption. The entering light penetrates a slight distance into and between the particles, and is reflected back after losing all those colours which do not contribute to its proper colour. Thus a mixture of Prussian Blue and Gamboge appears green to the eye because the blue paint absorbs all the red, orange, and yellow rays, and transmits the green and blue; while the yellow paint absorbs the violet, indigo, and blue rays. Hence the green rays are the only ones left to be reflected by both, and therefore the mixture appears green.

§ 10. **Surface Colours.**—Some bodies possess the peculiar property of reflecting one colour and transmitting another. Thus if an alcoholic solution of Aniline be allowed to evaporate on a glass slide, it will appear of one colour when seen by reflected light, and its complementary colour when seen by transmitted light. It is well known that gold-leaf transmits green light, and

reflects yellow rays. Cyanine, again, is purple by transmitted light, but of a peculiar plum colour by reflected light. This is due to a very dark absorption band in the green which absorbs this colour, and hence only the blue and red rays reach the eye.

§ 11. **Saturation.**—A colour is said to be saturated when it is not combined with white. If a beam of white light is made to pass through two coloured glasses of the complementary colours they appear black, since each absorbs all the colours except the one it transmits. Thus a pure red glass only lets red light through, and a pure green glass only transmits green light. Hence no light at all passes, and therefore when superposed they appear black when held up to the light. By this means a strong light may be reduced to any desired degree. In the same way, if a body of any colour be viewed through a coloured glass which absorbs the rays reflected by that body, the latter appears black. For example, a green body appears black when viewed through a red glass of the proper shade, since the green rays which are reflected are all absorbed by the red glass. On the other hand, a body viewed through a glass of the same colour appears of the same tint and hue as a sheet of white paper placed beside it. Hence the apparent colour of a body varies with the light by which it is viewed. Thus blues and greens are nearly indistinguishable in a yellow artificial light, such as a candle or gas light.

Yellow, as we shall prove later (p. 46), is not a primary colour, and it is formed in the spectrum by the overlapping of the red and green; but in the eye it appears to be a distinct sensation, since if one blinds one's eyes

temporarily by gazing for a long time at a bright Sodium flame through a spectroscope, one will observe that the red and green run into each other with no trace of yellow. This shows a remarkable fact, viz. that with ourselves yellow is a distinct colour, and not merely a mixture of red and green, such as is evolved by the fusion of those colours in Helmholtz' experiments. Furthermore, yellow light does not fatigue the eye for either red or green.

§ 12. **Transparency** and **Translucency.**—A body is said to be transparent when light passes freely through it with a minimum of absorption or reflection. It is said to be translucent when it only transmits a portion of the light, or scatters some of it. Thus frosted glass, horn, and tortoise-shell are said to be translucent. Some of the light is transmitted, but much is absorbed or scattered, so that objects are seen dimly through them. The substance through which the light passes, whether it be gaseous, liquid, or solid, is termed the Medium. If it be uniform in all respects, it is termed homogeneous; if not, it is called heterogeneous.

Transparency and translucency are only relative terms, since no substance is absolutely transparent or absolutely opaque. Below sixty fathoms the sea would appear pitch dark to the eye. Opaque substances, if sufficiently thin, will permit of some light passing through. Thus gold-leaf will transmit green light when held in front of a lamp, and direct sunlight will penetrate through the wood of any dark slide in sufficient quantity to fog a photographic plate if the sun be allowed to shine on the slide for a quarter of an hour, or even less. Iron, silver, and copper in very thin layers will

transmit some trace of light. An opaque body may be rendered invisible, and sometimes even transparent, by making it incapable of reflection. Thus, if a drop of Canada Balsam be placed on the ground-glass surface of a camera focussing-screen and a microscope cover-glass be gently pressed over it, the inequalities of the surface are filled up by the balsam. As this latter is of the same index of refraction as the glass, the screen becomes quite transparent and indistinguishable from a piece of clear glass at that spot. By this means the most minute details can be readily focussed-up by a magnifying glass. In the same way a piece of paper can be made translucent by smearing it with oil or grease. The air spaces and fibres of which the paper is composed have a different refraction from the intervening particles, so that, when the whole is saturated with oil, the indices of the parts are nearly equalised, and, the paper being rendered homogeneous, very little light is scattered. Again, if a glass rod be placed in a test-tube, the rod can be clearly seen; but if the tube be filled with Cedar oil, which has nearly the same refractive index as the rod, the part of the rod which lies in the oil becomes at once invisible. The absence of colour becomes of the highest importance in the case of photographic lenses. Thus a very faint tinge of yellow in the glass which is quite invisible when held up to the light, and only perceptible when placed on a sheet of white paper, will increase the exposure as much as 20 per cent. or 30 per cent. owing to the absorption of the blue-violet and ultra-violet rays.

§ 13. **Reflection** is the rebound of light-waves from the surface on which they are incident, into the original

medium. If the surface is polished and uniform the reflection is said to be regular, and the image of the source of light can be seen. If roughened or uneven the reflection is irregular, in which case the surface can be seen, but the image of the source cannot be seen. Mercury and polished silver reflect about 90 per cent. of the light, and a silvered mirror about 80 per cent. Fresh fallen snow is a good example of irregular reflection or scattering of light in which nearly all the light is reflected.

§ 14. **Shadows.**—When an opaque body interrupts a portion of the light within an illuminated area, it casts a shadow on the surface in front of it. A region which is screened off from a radiation or vibration of any kind is also termed a shadow, although the latter may be invisible to the eye. Thus we talk of "sound-shadows" and "electric-shadows" whenever an obstruction cuts off, or even diminishes, a series of vibrations. This may be observed the moment when one suddenly turns a corner from a noisy to a quiet street. The sound of the traffic in the street becomes at once lessened. One is in a "sound-shadow."

A shadow cannot produce an image, but only a silhouette of the object which obstructs the light from the source. In nature the source is never entirely a point of light, but consists of a very large reflecting surface which causes interposed objects to cast greatly extended half-shadows. These produce the well-known half-tones which so greatly add to the beauty of landscapes. Usually the sources are multiple, so that each half-shadow overlaps others, and thus breaks up the tones still further, so that when a surface is illuminated

from two sources the shadow becomes split up into four parts. First, two distinct penumbræ (half-shadows), one from each source, then a darker combined penumbra, and lastly, a dark umbra where no light reaches it is seen. These facts are of the greatest importance to artists, and deserve careful study. A somewhat similar phenomenon to the formation of shadows occurs when direct sunlight passes through a hole an inch or so in diameter. If the opening be square or irregular in shape, and the screen be perpendicular to the line of light the image will be square or irregular and sharply defined—provided the screen be not distant many times the diameter of the opening. On the screen being removed further back, the image will become larger, the margins less distinct, and the corners rounded off, until at length the image forms an imperfectly defined disc. If the screen is tilted to the axis of the rays the disc becomes oval. This explains why the images made by the irregular spaces between the leaves of a tree form circular patches of light on the ground when the sun is vertical, and become more and more elliptical as the sun descends. We may therefore say that when the screen is perpendicular to the axis of the sunlight through the aperture, and the distance of the screen not many times greater than the size of the opening, the image will be an exact copy of the aperture; but if the distance of the screen be large compared with the aperture, then the image becomes circular or elliptical, according to the angle at which the screen is placed.

In photography a knowledge of these facts plays a very important part. If one takes a group or portrait

out-of-doors, and there are trees in the immediate background, the apertures between the leaves will appear of their normal irregular shape if the lens be focussed on them. But—as is always the case when a group or figure forms the principal subject—the lens is focussed on the group, the trees will be more or less out of focus, and in consequence the apertures between the leaves will appear as round white discs in the print or positive. The larger the aperture used, the bigger will be the discs, and consequently they will become very obtrusive and spoil the effect of the picture. To avoid this it is necessary either to focus for a point behind the group so as to bring the trees into sharper focus, or to stop down the lens to a small aperture (which must never be greater than F/16 in any case), but F/32 is much to be preferred and will generally suffice to prevent the discs being noticed at all.

It is generally stated that the brighter the light the blacker will be the shadow cast. This is not strictly true, because if the light be very bright, such as direct sunlight for example, the greater part of the light is reflected from the sky and surrounding objects, and some of this will be thrown on to the shadow and adjacent parts, thus greatly reducing the contrast. The same thing happens when a photographic plate is over-exposed or fogged by light getting into the camera. The developed image will appear flat, and will give a dull picture. Now the light of the full moon is only the $\frac{1}{600000}$ part of that of the sun at noon, so that the reflected light is very feeble, and has very little effect on the shadow cast on objects by the moon. Hence the contrast between the shadow and the surrounding

surface is very marked, and the shadow appears inky black, which is never the case with a sun-shadow out-of-doors.

§ 15. **Coloured Shadows.**—If a sheet of white paper be pinned against the wall and illuminated by a light held a foot or so away, and a slip of red glass be held in front so as to throw a red image on the paper, the shadow cast by any opaque object (such as one's finger) placed between the red glass and the paper at the margin of the red light, will appear of the complementary colour, viz. green. In the same way a yellow glass will cause a blue shadow. Again, if in the twilight the light from a blue sky is allowed to fall into a room illuminated by a candle, and one holds an opaque rod in front of the latter so as to cast a shadow on a white surface, while another rod be held so as to cast a shadow from the blue sky on to the same paper, the first shadow will appear blue, and the second yellow, while the approximation of the two shadows will only intensify the contrast.

§ 16. **Shadows cast by Lenses.**—If a concave lens be held between a light and a screen in a darkened room, it will cast a dark central shadow just as if it were an opaque body. The transmitted rays being divergent they will be turned away from the spot around the axis of the lens and will be concentrated around the margin of the cone, thus forming a highly illuminated ring. The further the lens is removed from the screen, the larger and fainter will be the ring of light. A convex lens, on the other hand, if held at its focal distance from the screen will throw a bright central image (focus) on it, which is surrounded by a dark shadow,

since the rays are refracted towards the axis of the lens. Very little light therefore will reach any portion of the screen behind the lens, except around the centre.

A prism acts much in the same way as a convex lens. It throws a dark shadow behind it, since the light is deviated towards the base of the prism, outside which it forms a bright patch, which can be made to travel right away from the shadow if the prism be withdrawn further from the screen.

§ 17. **The Colour of the Sky.**—In the case of ordinary obstacles to the passage of light their size is enormously greater than the reflected waves of visible light (which vary from 0,3 μ to 0,7 μ, a "μ" being the $\frac{1}{1000}$ part of a millimetre), so that the ordinary laws of reflection bear no reference to wave-lengths when a wave is intercepted by such a large obstacle. The screening action is perfect, save for a small diffraction-band around its edge. Now it is obvious that a small obstacle will not be so effective as a screen for the long (red) waves, as for the shorter (blue) ones. When the source of light is low down, such as near the time of sunset, the long waves will be more freely transmitted than the short ones, and consequently as the sun sinks to the horizon, the white light from it will pass to yellow and then into orange and red. In the same way the snow on a distant mountain at sunset, will appear of a reddish tint. But as the long waves are the most freely transmitted the short ones will be most freely reflected and scattered. Hence, as we look at the sky, the light gradually becomes bluer towards the zenith, because the blue rays from that part of the sky are

reflected and scattered in all directions. This is the reason why the light from the sky appears blue, unless it is intercepted by clouds or mists.

In the same way we can explain the cause of the yellow tinge in fogs, especially if the sources of obstruction are due to large particles such as soot. Of course a great deal of the light is both stopped and modified by these obstructive particles in its path to our eyes. During the transmission, the rays of high refrangibility (*i.e.* the blue-violet rays) are stopped or hindered, while those of low refrangibility (*i.e.* the red-orange rays) are destroyed by scattering, hence the light which reaches the eye must be weak in rays from both ends of the spectrum. In other words the light is chiefly made up of blue and greenish rays. When the particles reach a certain size they will affect all waves equally, with the result that the light will appear white. In the low atmosphere the obstructive particles are largely due to dust and aqueous vapour, but in the high atmosphere they are probably due to extremely minute particles of matter such as very finely divided vapour or ice particles, or possibly to gas molecules (Rayleigh). The blue tints of a distant mist, the smoke from a cigar or a wood fire are all due to the same scattering of the light by exceedingly minute particles.

Tyndall formed an artificial cloud by precipitating the vapour of iodide of allyl through the action of light. He found that the particles gradually increased in size, and as they did so, the blue colour disappeared and the scattered light appeared white, as we have already stated above. If at this stage, the light which has now become polarised, be observed through a NICOL prism

held vertically, viz. in the position in which ordinary scattered light would be extinguished, the blue colour will appear again much richer than before. This deep blue was termed by Tyndall the "residual blue." Lord Rayleigh confirmed Tyndall's experiment, using for his dust-cloud a precipitate of sulphur made by adding a little very dilute sulphuric acid to a weak solution of hyposulphite of soda.

CHAPTER II

§ 18. The Evolution of Colour Photography

Colour photography may be said to date back to the time of the Farbenlehre of Goethe in 1810. It is there stated that "if a spectrum produced by a prism is thrown on to moist chloride of silver paper, if the printing be continued for fifteen minutes, I observe the following: in the violet the chloride is a reddish-brown (sometimes more violet, sometimes more blue), and this coloration extends well beyond the limit of the violet; in the blue, the chloride takes a clear blue tint which fades away, becoming lighter in the green. In the yellow, I usually found the chloride unaltered; sometimes, however, it had a slight yellow tint. In the red, or beyond the red, it looks a rose or lilac tint. The image of the spectrum shows beyond the red and the violet, a region more or less light and uncoloured. Beyond the brown band which was produced in the violet, the silver chloride was coloured a grey-violet for a distance of several inches. In proportion as the distance from the violet increased, the tint became lighter. Beyond the red, on the contrary, the chloride took a feeble red tint for a considerable distance."

It was not until 1868 that any satisfactory explanation of these phenomena was forthcoming. In that

year Zenker showed that colours could be produced by stationary light-waves formed in the layer of silver chloride. It was further found that many body (pigment) colours were highly sensitive to light, becoming bleached by its action. Wiener showed that a light-sensitive substance can only be bleached by those rays which are absorbed by it, all other rays being either transmitted or reflected. In fact, a substance is called red because it reflects red rays and absorbs green and blue ones, and so for other colours. If, therefore, any substance happens to be sensitive to the action of different wave-lengths of light, it must be due to rays of such colours as will be absorbed by the body. Quite recently Dr. Smith has made use of this principle in his Uto-color bleach-out paper (see Chapter XI.), and Szczepanik, Neuhaus, Liesegang, and others are still working in the same direction.

In 1890, or 22 years later, Lippmann confirmed Zenker's discovery, and succeeded in producing interference pictures by placing a very thin chloride emulsion plate in contact with a layer of mercury which acted as a reflector. By this means the light-waves from the object which pass through the film meet previous waves reflected by the mercury mirror, and so produce the interference phenomena. Thus the silver chloride is changed at the spot where the crest is increased, but unaltered at the spot where the wave is neutralised.

Meanwhile Vogel, Obernetter, Eder, and Abney were experimenting to increase the range of the collodion plate affected by the action of coloured lights. By bathing a plate in Eosin, Vogel found that he could extend the

sensitivity of the plate from the yellow-green as far as the orange, and Abney, going a step further, extended it to the red by means of Cyanin blue. This was soon applied to the gelatine plate, and so orthochromatic plates came into vogue. Later on Aethyl red was employed by Miethe, and finally Pinacyanol was applied, which enabled plate-makers to produce a panchromatic plate, *i.e.* one sensitive to *all* the colours of the visible spectrum, or roughly speaking corresponding to wave-lengths from 400 to 700 $\mu\mu$ (micromillimetres).

The discovery of the power of certain dyes to render the photographic plate sensitive to all visible colours was the one step needed to render the methods of colour photography and colour printing possible. The early Daguerreotype plates were only sensitive to the violet, the blue, and a little of the green. The gelatine plates, before the action of dyes was known, were sensitive to the violet, blue-green, and a little of the yellow. Eosin and Erythrosin dyes extended their action through the yellow and orange, while Aethyl red, Cyanine and Pinacyanol brought the sensitivity nearly up to the end of the visible red.

Gradually our ideas of colour were built up. The early suggestions of Thomas Young (1773–1829), elaborated by Helmholtz in Heidelberg, established the new theory which has been called the Young-Helmholtz theory of colour vision. Clerk Maxwell in Cambridge further exemplified this theory and showed that every possible colour and shade of colour was either a blue-violet, a green, or a red, or else a mixture of two or of all three of these colours. Ducos du

Hauron in France, and Ives in America, applied these facts in practice by making three separate negatives of the coloured object through a red, green, and blue glass respectively. Then positives were made and the three projected on to a screen through the same glasses and made to coincide. Ives went further, and took stereoscopic pictures in the same way and combined the chromograms by means of his Kromskop instrument. In this way the picture was seen, when brilliantly illuminated from behind, in all the original colours and in stereoscopic relief. Later, relief blocks were made on bichromated colloids taken through the same coloured glasses, and impressions made by means of the complementary colours either from inks or dyes, and prints made one over the other on the same support, or on separate thin films which were superposed. In this way facsimiles in colour were produced which could be viewed by reflected light, or bound up as transparencies to be seen by transmitted light. In the same way all the beautiful coloured "process" prints are obtained. This fundamental method of producing prints has been elaborated in various ways by Dr. E. König, and by Sanger-Shepherd; also by the Rotary Company's stripping pigment process, the Carbon, Collotype and Raydex methods. In the year 1904 Messrs. Lumière obtaineddirect tran sparencies in colour by means of screens coated with starch grains dyed in the three primary colours, and coated with a panchromatic emulsion. This method has been followed by others, based on the same principle; but instead of covering the glass with coloured starch grains, the makers have ruled the glass with fine lines or dots, or a combination of both,

in the three primary colours. Such plates yield exceedingly brilliant pictures and very pure and intense colours, but they do not possess the softness or range of hues and tints that the autochrome plates do, nor are the colours so true to nature.

At length, after several years of experimenting and many disappointing failures, bleaching-out papers have been produced by Szczepanik, and especially by Dr. J. H. Smith, by which copies of colour positives can be printed in direct sunlight, which may be fixed and mounted like ordinary photographic prints. Such copies present the great advantage of being viewed by reflected light, which permits of their being hung on the wall, or pasted into an album. It cannot be denied that these pictures are far from perfect, the colours are impure and the whites never come out as pure whites, but the process is being improved every day, and we have no reason to doubt that in a comparatively short time such pictures will take a prominent position on the walls of our photographic exhibitions.

Finally we must mention the achievement of Messrs. Urban and Smith, and later by Gaumont, by which kinematograph pictures in colour can be projected on to the screen, whereby the illusion of objects in motion is greatly increased. This method will be found described in detail in Chapter XII.

CHAPTER III

§ 19. The Eye compared with a Camera, and the Retina with a Colour Plate

The human eye is a spherical ball almost exactly one inch in diameter, closely resembling a plum, the stalk of which represents the optic nerve. This latter is a round hard cord measuring $\frac{1}{8}$ of an inch in diameter, made up of an immense number of bundles of nerve fibres, surrounded by a tough sheath. If traced backwards it will be found to pass through a hole in the back of the orbit where it enters the skull, and immediately to cross obliquely towards the middle line, where it becomes intimately united with the nerve of the opposite side. Here it again separates, the halves of each nerve fusing together to form a flat band. This band passes along the under surface of the brain, into which it soon enters, and becomes lost in the great optic nerve ganglia which are situated in its substance. There the fibres become intimately connected with the brain-cells, which interpret the visual impulses projected from the eyeball, and enable the person to perceive mentally the images formed at the back of the eye. The eyeball consists of three coats. 1st. An outer thick tough fibrous coat, the Sclerotic, which serves to keep the eye in shape, and protect the delicate coats inside it. 2nd. A dark layer, made up almost

entirely of a network of blood-vessels, which serve to nourish the parts around. And 3rdly the Retina. This is a highly complicated nervous layer formed by the spreading out of the fibres of the optic nerve over the entire surface of the back half of the eye. It forms

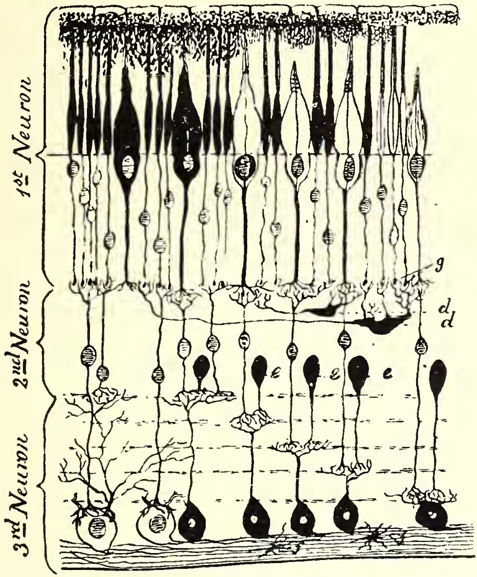


FIG. 2.—Semi-diagrammatic vertical section of retina showing the layers and systems.

the receptive layer on which the images of external objects are perpetually being formed. Each individual fibre is connected with a large cell called a ganglion-cell, from which one or more fibres pass directly backwards in a very complicated manner. These ultimate nerve fibrils divide up into a number of fine short

branches, or arborisations as they are called, which are connected with other branches from a second set of nerve fibrils, and which terminate in a series of peculiar bodies called rods and cones. These form the terminals of the retina. Seen from above, they

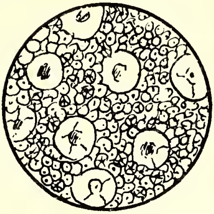


Fig. 3.

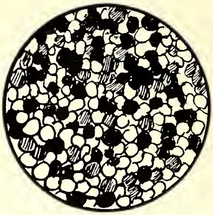


Fig. 4.

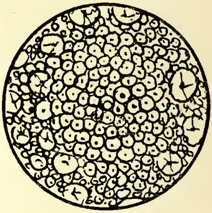


Fig. 5.

Fig. 3.—Cross section of the rods and cones in the retina of a human eye, taken midway between the periphery of the retina and the yellow spot. The small discs are the rods, the large ones the cones. Observe that the dots in the centre of each circle (which represents a cross section of a rod or cone) are kept in the middle of the surrounding insulating substance by radiating fibres. Each dot is the cross section of an axis cylinder (terminal nerve fibril). From a photograph of a microscopic section prepared by the Author.

Fig. 4.—Represents a magnified fragment of a Lumière screen. The black discs represent red grains, the shaded green-coloured grains, and the white discs blue-violet grains.

Fig. 5.—Cross section of the cones at the Fovea (centre of the yellow spot); cones surrounded by a single layer of rods are to be seen towards the circumference. From a microscopic section made by the Author.

form a mosaic pattern which is made up of large discs surrounded by one, two, or more rows of small discs. These are closely packed together, and are so numerous that they amount to about 5,000,000 in all. The ends of the rods and cones lie in contact with a dark layer of six-sided cells, which are filled with minute granules,

and have a network filled with fine oat-shaped crystals which finds its way under the action of light between the ends of the rods, and retracts again in darkness. Their function seems to be to prevent halation, while the function of the six-sided cells is to secrete the retinal purple—a remarkable chamois or purplish-coloured substance in which the ends of the rods are bathed. Its use is not known, except that it is in some way connected with vision, and that it bleaches when exposed to light.

Exactly in the centre of the retina, and on the line of the visual axis at the posterior pole (back of the eye), is a dark reddish spot, about 2 mm. or 2,5 mm. in diameter—the macula. This is the area of most distinct vision, and here the rods become greatly reduced in number, until, at the centre where there is a tiny pit, there are no rods at all, but only cones. These are not cones in the ordinary sense of the word, such as are to be found over every other part of the retina, but long narrow cylinders closely packed together, so as to get as many as possible in a small space. By this means the sensitivity of the spot is largely increased, since the image of an object will cover far more cones than if it were to be formed anywhere else on the retina. We therefore only see distinctly over the macula area a roundish patch about two mm. across, and which subtends an angle of about 5 degrees in the field of vision. Critical vision is confined to the pit itself, which is a much smaller area still; in fact, it occupies in the field of vision an angle of less than 1 degree (about 8″). So that it may literally be said that we read with our maculæ only,

and not with the whole of our retinæ, although we can get a general impression of objects over the whole retinal field. As a matter of fact we only see one object at a time, but by revolving the eye very rapidly both up and down and horizontally, everything can be seen satisfactorily. It is to our advantage that we do not see everything sharply at the same moment, otherwise we should see such an overwhelming mass of detail, that we should be quite unable to take the view in, or pay attention to anything. As it is we see one point after another in succession, and by combining the sum of all the points looked at, we receive the impression of the whole view sharply defined. In all the lower mammals below the monkeys we find no trace of a macula, but, on the other hand, we find an extended sensitive area. So that most of the animals do not see so well as we do over a small area, but they see much better over a larger one. This is the reason why no animal (or, more strictly speaking, no mammal) below the monkeys habitually moves its eye, but if it wishes to look at an object in another direction it almost invariably turns its head, but not its eye. Any one who takes the trouble to watch the eyes of any animal at any Zoological Gardens can prove that fact for himself.

If you look at Fig. 2 you will observe that each cone has a nerve fibre exclusively belonging to it, which although twice interrupted in its course by arborisations, nevertheless permits the current to pass along the continuation of the fibre direct to the sensorium. Moreover, the nerve fibril is furnished with a relay ganglion (*e*, *e*, *e*, *e*, Fig. 2). The rods, on the other hand, have not

each a separate nerve which connects them with the brain. If you examine the figure carefully you will notice that from 2 to 10 or more rod fibrils are embraced by a single arborisation, so that the square of these numbers will represent the number of rods which have united to convey a single impression to the brain. Hence 100 or more rods will only convey the impression of the same amount of detail that a single cone will effect.

It is the cones, therefore, which carry the image-forming vibrations to the sensorium. The function of the rods appears to be twofold. 1st. They act as dampers to the acuity of vision outside the macula area, so as to allow the mind to be concentrated on the area of fixation. 2nd. By occupying very little room, and being very numerous, the rods, although they do not help the definition of objects, enable the eye to perceive dimly lighted objects, which the scattered cones alone would only perceive very imperfectly, or not at all. (See the Purkinje Phenomenon, § 25.)

Occupying the whole of the front of the eye is a clear transparent modification of the sclerotic coat known as the Cornea. Inside this is a coloured membranous ring—the Iris, having a black circular aperture in the centre—the Pupil. Behind the Iris, and resting against it, is a highly refractive curved body—the Lens. Between this lens and the cornea is a space filled with a clear watery fluid—the Aqueous. The remainder of the eye is filled with a clear, colourless, thin jelly known as the Vitreous Humour. The eye thus forms a spherical camera similar in many respects to a photographic camera. In the eye the lens system is

formed by two lenses: 1stly, the cornea, which is a spherically curved shell of dense transparent tissue; and 2ndly, the crystalline lens, which is a strongly curved biconvex lens placed a little distance behind it, and separated from it by a watery fluid—the Aqueous (see Fig. 6). Between the two lenses lies the Iris. This forms the variously coloured membrane which contributes so largely to the beauty of the eye. It forms a perfect iris diaphragm, having a circular aperture in the centre, which appears black to the observer. This contracts or dilates automatically with the increase or diminution of the light. At its full opening, it measures from 6 to 8 mm., or in some people even 10 mm. across. The focal length of the lens combination *in situ* is 15,5 mm., or about 3/5 in.,[1] so that at its full opening it works at F/2,5 or F/2, and in some cases even F/1,5, and in a very bright light at about F/8. This fraction is understood to mean the ratio-aperture of the lens, *i.e.* the ratio between the focal length of the lens and the diameter of the stop or aperture. Thus, supposing the lens to have a focal length of 8 inches, and the diameter of the stop to be 2 inches, the ratio aperture would be as 8:2, and we should speak of the lens as working at

[1] This is the case if we measure the focal length from the nodal point (situated at the posterior pole of the crystalline lens) to the retina. If we take the focal length to be the distance from the posterior principal plane to the retina (as is done when working out the measurements of the eye), then the focal length will be approximately 20 mm. But the former distance is the most convenient for our purpose, since the distance between the nodal point and the retina is the one used for determining the magnifying power of the eye and the size of the retinal image.

F/4, and the same applies to every other focal length and stop.

The camera lens usually consists of two lenses (or rather of two cemented combinations), and there is also an iris diaphragm working between them. The ratio-aperture varies from F/3 in a very rapid portrait lens, or F/8 the full aperture of a rapid rectilinear lens, to F/45 its smallest aperture. Hence the eye has a great advantage over all manufactured lenses as regards rapidity. Moreover, a camera lens rarely embraces an angle of over 100°, whereas the eye embraces an angle of 160°, or about 170° when both eyes are open. The eye camera is a rigid one, and it is adjusted for various distances by altering the curve of the front surface of the lens. This is effected by means of a circular band of muscular fibres embedded in the coats of the eye, and surrounding the edge of the lens. When this circular muscle contracts, it relaxes its tension on a ligament which presses against the front of the lens, thereby allowing it to bulge forward, and thus increasing its refractive power. Hence if the eye were previously focussed for infinity, it would now be adapted for nearer and nearer objects in direct proportion to the amount of contraction of the ciliary muscle, and consequently to the amount of bulging forward of the front surface of the lens. In the photographic camera the same result is obtained by racking the lens further away from the screen.

In the camera the rays come to a focus, and thus form a picture on the ground-glass screen, or on the sensitive plate when that replaces it. In the same way the rays are brought to a focus on the retina

(R, Fig. 6) at the back of the eye by means of the lens system, the image falling on a fine mosaic consisting

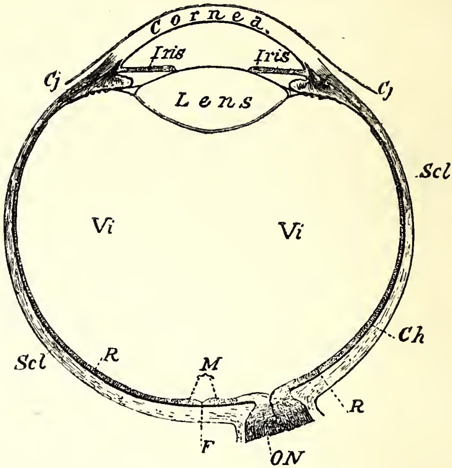
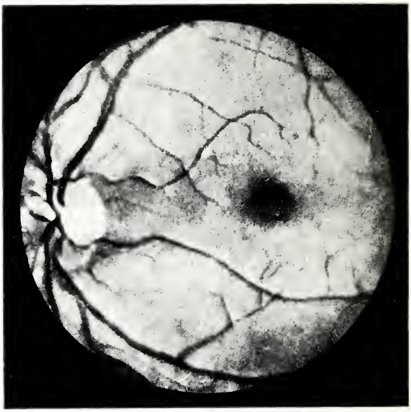


Fig. 6.—Horizontal section of the human eye through the Macula and optic nerve: magnified × 2.

Cj. Conjunctiva or Membrane which spreads over the eye to the rim of the Orbit.
Scl. Sclerotic or fibrous capsule of the eye.
Vi. Vitreous humour (or jelly) filling the cavity behind the lens.
Ch. Choroid or vascular layer which secretes the visual purple and also nourishment for the rods and cones.
R. Retina, or expansion of the optic nerve adapted to receive impressions of light. This is a complex nervous structure, the fibres of which terminate in minute rods and cone-shaped bodies. They are closely packed together, forming a mosaic when viewed on the surface.
M. Macula (yellow spot), the highly sensitive area of the retina.
F. Fovea or centre of the Macula.
ON. Optic Nerve (cut short) leading to the brain.

of a layer of rod and cone terminals. Behind this mosaic is a layer of dark pigment cells which secrete

Plate II.



Normal Fundus (background of the eye) of a man forty years old.

By permission of Prof. Dimmer, of Gratz.

The oval patch on the left is the disc or head of the Optic Nerve. A little to the right of the centre is a dark round patch. This is the most sensitive part of the eye, and comprises the macula (yellow spot) area. In the centre of this patch is a depression or pit known as the fovea. The fixation point or region of perfect vision is only to be found at the fovea. The dark lines are due to blood-vessels, arteries, and veins, which enter the eye near the centre of the disc and are distributed over the greater part of the retinal background.

To face p. 43.

the visual purple, and behind these cells is a dense layer of blood-vessels held together by tissue, and known as the choroid (Ch). The analogy between the way in which light acts on the retina and on a Lippmann film is very close. In the Lippmann camera the light passes through the lens and sensitive chloride-of-silver film, and is reflected from the mercury mirror in contact with it behind. In the case of the eye the light passes through the lens and retina and is reflected from the concave spherical mirror which constitutes the choroid, directly on to the ends of the rods and cones, thus giving rise to image-forming vibrations which pass along the fibres of the optic nerve (ON) to the brain, where the psychic transformation into a visual image takes place. It is conceivable that if reflected rays meet the entering rays half a wave-length later in a different phase, interference phenomena will be produced in the eye.

In colour photography we place a colour screen with red, green, and blue-violet dots, patches, or lines in front of the sensitive film. In the eyes of mammals there are screens[1] with zones of brilliant colours—emerald green, gold, vermilion, scarlet, ruby, orange, yellow, brown, blue, violet, and purple, in a similar way. In man and many other mammals, birds, and reptiles we find a monochromatic vermilion or scarlet colour-screen. In a few animals (*e.g.* albinos) we find a creamy white fundus,[2] interspersed with patches of

[1] These coloured screens are situated in the front part of the choroid, immediately behind the retina, and in some animals constitute what is known as the Tapetum Lucidum (Brilliant layer).

[2] Or background of the eye (see Plate II.).

vermilion, which reflects all colours, and in a few we find a chocolate-coloured screen, but in no animal is there a black screen to be found, which ought to be an essential requisite if the usually accepted theory were true that the image of external objects is projected on to the layer of rods and cones, instead of being formed on the mirror and reflected back again on to their ends as we have stated.

The photographic plate is coated with a thin layer of gelatine and rendered sensitive to light by being impregnated with Bromiodide of Silver. In the eye we have a mosaic made up of the ends of the retinal nerve fibres on which the image of the object seen is focussed, and which is rendered more sensitive to light by the presence of the visual purple which is constantly being secreted and in which these nerve terminals are bathed.

§ 20. **Reason why the Yellow Spot is Yellow.**—In taking a photograph through any kind of colour-screen plate, it is necessary to restrain the intense action of the blue-violet rays by placing a yellow colour-filter in the path of the rays in front of the screen. In our own eyes, and in those of all other vertebrates, we have a yellow colour-filter interposed for the same purpose throughout the entire extent of the retina. This occurs in the narrow-meshed plexus (Ch) of the capillary vessels which lies immediately in front of the sensitive layer. The only exception is at the fovea, *i.e.* the tiny pit at the centre of the macula (M) or yellow spot as it is called. Here there are no blood-vessels, and nature therefore has placed at this spot a yellow pigment behind the sensitive layer which serves the same purpose even

PLATE III.

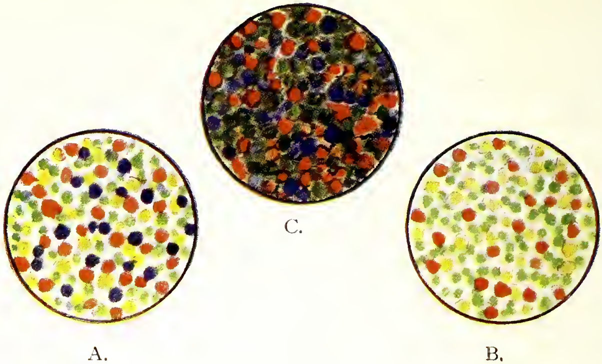


Fig. I.

A. Appearance of the coloured oil globules in the retina of a tortoise's eye, as they would appear if seen from above looking towards the choroid, × 700. G. L. Johnson.

B. Do. do. Appearance of the oil globules in the retina of a domestic fowl, × 500. G. L. Johnson.

C. Appearance of the starch-grain layer in an Autochrome plate, × 140. G. L. Johnson.

Fig. II.

Vertical section of a pigeon's retina, showing appearance and position of the coloured oil globules, × 870. (After Prof. v. Greeff's monograph in the Graefe-Saemisch Handbuch der Gesamten Augenlik.)

To face p. 45.

more effectively.[1] If there were no yellow pigment at the macula, when looking at a white sky or white surface we should see a blue-violet disc projected in the line of regard in front of our eyes, corresponding to the non-vascular area in the centre of the visual pit.[2]

The amount of blue-violet absorbed by the capillary screen is very considerable, extending from G to K (4300 to 3920), and resembling in its colour and action that of a Lumière screen.

§ 21. **Remarkable Similarity between the Autochrome Colour Screen and the Colour Screen in certain Birds and Reptiles.**—If we examine a Lumière Autochrome or a Thames colour plate with a magnifying glass, after having stripped off a piece of the sensitive film, we notice the whole surface is covered with a mosaic of red, green, and blue-violet dots. Now all the birds and most of the reptiles show no trace of vessels which nourish the retina, which we find so highly developed in most of the mammals. In the majority of the mammals we find the retina nourished by a rich supply of blood-vessels and capillaries, but in all the birds and most of the reptiles this blood-supply is completely wanting, the nourishment being derived by osmosis, or, in other words, by a soaking-through or percolation of choroidal lymph-plasma through the layers of the retina. Consequently they have neither a brightly coloured fundus nor any *tapetum lucidum* (*i.e.* a reflecting colour-layer) of

[1] The Author ventures to offer this theory as the true explanation why the fovea is yellow. As far as he knows, it is here advanced for the first time.

[2] See the Author's work, "Pocket Atlas and Test-book of the Fundus Oculi," Adland & Son, London, 1910.

any kind such as we find in most of the mammals; but instead, some of them are provided with a mosaic of oil globules. These latter are tiny droplets of a highly refracting coloured substance, and they are situated just where the cones penetrate the external limitating membrane, and consequently immediately in front of the sensitive layer (*i.e.* tips of the cones) where they receive the light impression. Their position will be seen to be almost in contact with the pigment-laden filaments which pass between the separate nerve ends. See Plate III.

It will also be noticed that these coloured drops form four rows. First a yellow, then a red, then another yellow, and lastly, a green row. In the tortoises we find in addition a blue-violet row. Thus Lumière's discovery has been forestalled by the reptiles and the birds. But why should there be a yellow layer of dots? Are not the three primary colours enough? In coloured light mixing by spectroscopic colours, Clerk Maxwell, Helmholtz, and Abney successively showed that the three primary colours, red, green, and blue-violet were sufficient to produce all the different shades of colour; and in colour printing likewise every colour could be produced by these three primaries if only a shade of grey were added, as Mr. Handel Lucas has so ably pointed out (see "British Journal of Phot.," supplement, 1912, pages 43 and 55); although I agree with Messrs. Newton and Lucas that in this latter case the use of grey is only necessary on account of the imperfection of our printing inks. But the perception of colour by the eye differs in one respect from the purely physical production of colour. In the latter case

yellow is produced by the mixture of green and red in certain proportions. In the eye, however, yellow is a distinct colour sensation. This fact has been made use of to make a special form of test for colour blindness, by which a pure yellow comprising the D line is transmitted through the slit of a spectroscope, and a second yellow is made to match by employing two other slits, one transmitting a red beam, and the other a green beam. The candidate is then required to adjust the green slit until by overlapping, the red together with the green forms a perfect match with the uncombined yellow. If the observer were colour-blind to red or green, the match could not be made. The writer has repeatedly suggested that a screen-plate of four colours would give a more perfect rendering of nature than the usual three colours.[1] Perhaps some colour-plate makers will carry out the experiment.

§ 22. **Colour Vision and Colour Blindness.**—In order to understand the rationale of three-colour photography, it may be useful to some of our readers if we try to explain the nature of colour vision and colour blindness.

The light impression gives rise to three sensations which are quite distinct—a light sense, a form sense, and a colour sense.

The first is the faculty of distinguishing illumination and its degrees of intensity. This is effected in the most simple case by the presence of pigment spots in the cuticle of an animal or plant, and forms the most rudimentary of all forms of eyes.

[1] According to Hering's theory of colour visions these four colour sensations must be present together with white and black, thus forming three opposing groups, viz. red and green, yellow and blue, and white and black (see Appendix, p. 261).

The form sense is a higher development of the sight faculty, and needs a transparent refracting body to form a real image, and nerve terminals to convey the collected impression to the animal's brain. This image may be quite independent of colour.

The colour sense constitutes a still further development of vision, which we will now discuss.

As was first shown by Newton, white sunlight can be resolved, by means of a prism, into six distinct colours, viz. violet, blue, green, yellow, orange, and red. These are the only pure spectrum colours which most of us can perceive, although some people can see indigo as a distinct colour, thus making seven colours in all. We have reason to believe some animals can see other colours beyond the range of this spectrum. We have stated that all the colours in nature can be formed by suitable admixtures of blue-violet, green and red, while white is formed by the action of these three colours together. Black is not a colour at all, but is caused by the absence of all colour sensation.[1] Thus, if these three primary spectrum colours be projected on to a screen by *separate* lanterns and then superposed, the result is a white disc of light, the colours being *added together* (additive method). If, now, you put a red glass in front of a lantern emitting white light, on the top of that a blue, and finally a green glass, since each glass absorbs all the colours except its own, no light at all will reach the screen, and the result will be a black patch, the colours being *subtracted* (subtractive method). But three coloured lights are not really necessary to produce black, since any two complementary coloured

[1] See end of this Chapter.

lights or glasses if superposed will effect the same purpose by subtraction, that is to say, each colour will absorb (subtract) all the colours of the spectrum except its own, and in the same way any two complementary coloured lights if mixed will produce white (by addition), as can be proved by the reader for himself.

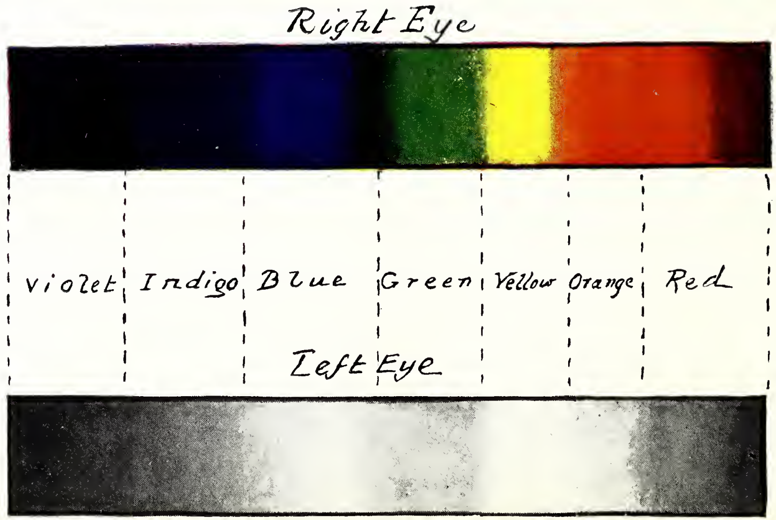
If you look steadily for a minute at the red part of the spectrum in a spectroscope illuminated by a very intense light, in which the rest of the spectrum is cut off, and then look at the entire spectrum through another spectroscope moderately illuminated, you will see the blue-violet and green bands; but the green runs right into the yellow as far as the C line, where it suddenly ends. The yellow will be found to have entirely vanished—it is all green. Now rest your eyes for about ten minutes and repeat the experiment with the green part of the spectrum, and you will notice that you can again see three colours, but they are changed to violet, blue, and red. The green has quite gone and the blue runs straight into the red. In the same way you can blind your eyes to blue, and the green and violet will be seen to run into each other. Again, you may blind your eyes to the violet. This is more difficult, as it requires a longer gaze and a very intense light. The blue will still be visible, but it ceases abruptly at the violet end. Lastly, if you blind your eyes to the yellow by gazing for a long time at a bright sodium flame, you will observe that the red and green will run into one another. This forms yet another proof of what we stated in the previous paragraph, viz. that yellow is a distinct colour

and not merely a mixture of red and green, as is evolved by the fusion of those colours in Helmholtz' experiments. Furthermore, yellow light does not fatigue the eye for either red or green.

To sum up. A red-blind person sees violet, blue, and green. A green-blind sees red, blue, and violet; a violet-blue-blind sees a little blue, all the green, and a little red, but no yellow, since the green and red have met together.

Unfortunately, it has been impossible up to the present to imitate a pure spectrum violet, or to find it in natural colours. According to Dr. Edridge-Green, the corn-flower and some varieties of Lobelia nearly approach to it, so that we have to content ourselves with a blue-violet dye, *i.e.* a mixture of violet and blue, which is the closest imitation of violet that we can procure. It is quite possible that some dye will yet be found that will give us a pure violet, as well as a pure blue. The other colours are much easier to find. Thus, ruby glass and the purple of Cassius (oxystannate of gold) form fairly pure reds. Sulphur and bichromate of potash make good yellows, and a saturated solution of ammoniacal sulphate of copper makes a nearly pure blue. But the reader must not go away with the idea that these primary colours stop abruptly. They each run on far beyond the point at which they appear to stop in the spectrum. "In other words, the red and green sensations overlap, as do the blue and green and also the violet and blue, so that we must take the middle point of the combined overlapping as the natural boundary between the adjacent sensations" (Burch).

PLATE IV.



Facsimile of a drawing of the spectrum viewed through a spectroscope by a patient of the author's, depicted as seen with the right eye (normal colour vision). The lower picture is a facsimile of a similar drawing viewed in the same way, and depicted as seen with the left eye (total colour blindness). The vision as tested by test-types was nearly normal. The two drawings were made by the patient in the presence of the author on the same day.

To face p. 51.

As to how we see colours we are quite ignorant. Most physiologists assign the perception of colour to the cones, leaving to the rods the function of seeing feeble luminosities. Helmholtz' theory, that certain cones respond to the stimulus of red undulations, others to green, and others to blue-violet, will not bear close investigation. Some physiologists assign the sense of colour as well as perception of form to the action of the visual purple. This, again, is open to objection that there is no visual purple at the fovea, or in certain animals, *e.g.* bats, but this difficulty is got over by assuming that other secretions, such as visual white, visual green, or visual yellow, take on the same function. The author found all these bodies in the retinæ of animals. Edridge-Green has suggested that the visual purple flows into the fovea during the act of vision. This theory explains certain phenomena, but is not accepted by many physiologists. Again, we have reasons for believing that there is a colour centre in the brain. A remarkable case bearing on this point occurred in the author's practice. The patient was suffering from a form of creeping paralysis which gradually affected the limbs of the left side. At the same time, as more and more of the muscles became paralysed, the sense of colour slowly vanished in the corresponding eye, until ultimately the patient could see no colour at all, everything appearing black, grey, and white, like an engraving. This was tested by getting the patient, who was a good water-colour painter, to make a coloured drawing of the spectrum, first with the sound eye and then with the colour-blind one. Notwithstanding the absence of all sense of

colour, vision was hardly affected at all, and the colour sense remained perfect in the right eye, while that of the left eye never returned (see Plate IV.).

Colour blindness, which affects about four out of every hundred people one meets, may be due to a deficiency in light perception of a portion of the spectrum, usually in that part which lies at the red end. Dr. Edridge-Green has classified colour-blind people according to whether they can perceive six colours, five, four, three, two, or only one colour. Thus, one who distinguishes all six colours, or a hexachromatic person, may be considered as normal. One who distinguishes five of the spectrum colours confuses orange-red and red, orange-yellow and yellow, rose-red and red, purple-violet and violet, bluish-green and green. A tetrachromatic person sees only four distinct colours. He confuses red, orange and rose-red, greenish-blue and green, and pure blue and violet. A trichromatic person sees only three distinct colours. He confuses red, orange and rose, most of the yellows, and blue, violet, and purple. He also confuses rose, grey, and green, and many browns, as well as bluish-greens and greens. A dichromatic person sees only two colours. Thus, red, orange, yellow, and green, all seem alike, as do all blues and violets. He also confuses blue-green, purple, and greys. A monochromatic person sees no colour at all. Everything appears as impure whites, blacks, or greys. One- and two-colour cases are exceedingly rare.

The Young-Helmholtz theory fits in better than any other with the phenomena relating to colour photography, but it by no means harmonises with all the facts connected with colour vision. Thus, a dichromatic

red-blind person ought to see green best, whereas he sees yellow most distinctly. Again, the phenomena of after-images cannot be explained by this theory. Nor does it account for the additive and subtractive formation of white and black sensations in persons possessing only two or three units of colour perception. Furthermore, a pencil of coloured light, *e.g.* light which has passed through a coloured glass focussed on a very minute area of the macula, will produce the sensation of white, whereas it ought to give rise to a very decided sensation of the colour.

Again, as we have already pointed out, yellow is a distinct colour and not merely a combination of red and green coloured lights.

Lastly, if it were true that the retina consisted entirely of three groups of fibres, corresponding to red, green, and blue-violet sensations, how can persons blind to all these colours have nearly normal vision? and how can they see white objects as white? [1]

§ 22A. **The Visual Purple.**—We are still in doubt as to the function of the substance secreted by the outermost layer of the retinal (hexagonal cell) layer, called by Boll the "visual purple." According to some writers, who have made it a special study, vision depends entirely on its decomposition. The author's theory, which he thinks harmonises best with the facts, is briefly as follows: We know that this visual purple is rapidly decomposed in the presence of bright daylight and at the same time is continually being re-formed. Now, in bright sunshine this visual purple is used up as fast as it is secreted, so that if one steps into a dark room, the purple having

[1] See Appendix, p. 259, "Theories of Colour Vision"

been nearly all used up, one cannot see anything, and one has to wait a minute or two until the purple accumulates, which it quickly does. As the amount increases the vision improves, or, to use a familiar expression, the eyes get accustomed to the dim light. If, now, one steps out of the room into the bright sunshine the amount of accumulated purple generates so much visual energy that one is dazzled and almost blinded for the moment until the superfluous store of purple is decomposed. It may be objected that bats, which can certainly see in a very dim light, have no visual purple at all, but then they possess a buff-grey visual substance which answers the same purpose.

§ 23. **On the Meaning of the Sensation called Black.**—We have stated on page 48 that black is not a colour at all, but is caused by the absence of all colour sensation. This requires some qualification. We must distinguish between the absence of all light stimulus on a portion of the active normal retina, capable of conveying a colour sensation to the brain, and a gap in the field of vision produced by a part of the back of the eye not adapted for conducting a sensation to the brain.

The former gives rise to the appearance or sensation of black, whereas the latter does not give rise to any sensation whatever, so that the gap is not perceived. For example, our visual field is not bounded by black; on the contrary, it fades away imperceptibly into nothingness in all directions. Again, the head of the optic nerve or papilla (ON, Fig. 6) occupies a space in the field of vision about the same size as that of the macula area (see bottom of page 37). It is known as

the blind spot, and is situated a little to the outer side of the line of regard. Although light of every colour reaches this spot at the back of the eye, it does not appear as a black or white disc in space, since we are unconscious of any defect there. If, however, we shut the Right Eye, and hold our right finger about a foot away, exactly in the line of vision, and then place our left forefinger close to it, and move it slowly outwards to the left-hand side (without moving the head or line of regard), the top of the finger will suddenly disappear and then reappear again. This is due to the gap in the field of vision due to the blind spot. Another simple experiment which shows the same thing is to draw a black cross and a dot on a sheet of paper, about the distance between the pupils apart (61 mm. or $2\frac{3}{8}$ in. apart).

Fig. 7.

Close the right eye and hold the paper so that the round spot is in the line of vision of the left eye, about 12 inches away. If now the paper is slowly withdrawn or approached towards the eye a position will be found at which the cross becomes invisible. On withdrawing or approaching the paper from this position the cross will again become visible. By this means the area of the blind spot can be calculated or mapped out. It will be found to be about 2·25 mm. in diameter.

CHAPTER IV

§ 24. The Sensitiveness of the Photographic Plate as compared with the Eye to different Parts of the Spectrum

In order to demonstrate the effect of different colours of the spectrum on a sensitive plate, we may draw a

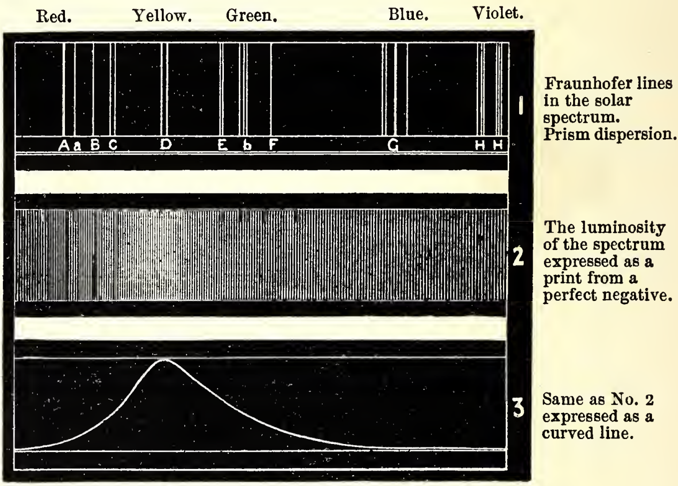


Fig. 8.

curve on squared paper in which the height of the curve (ordinate) represents the intensity of the light, while

the distance it is projected horizontally (abscissa) represents the scale of wave-lengths of the different colours of the spectrum.

In Figs. 8 and 9, a curve is shown representing the sensitivity of the eye to different parts of the spectrum of sunlight. It will be seen that the curve rises rapidly from the red towards the yellow, and slopes very gradually on the blue side, there being hardly any intensity at the blue end.

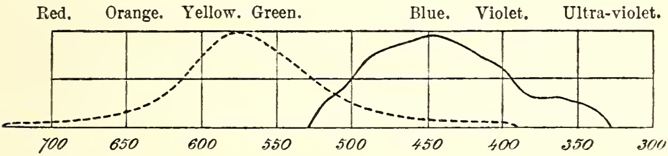


FIG. 9.—Luminosity Curve of Eye (dotted line). Ordinary Non-colour Sensitive Plate (plain line). The numbers express the wave-length of light in micromillimetres ($\mu\mu$).[1]

Now, when a photograph of the solar spectrum is taken with an ordinary plate, we shall find the curve, which is altogether wanting at the red end, rises to a maximum in the blue, where it is prolonged far beyond the range of visibility of the human eye (Fig. 9).

By bathing the plate with one of the isocyanine dyes (pinacynanol) it has been found possible to extend the curve of sensitivity into the red (Fig. 10), and produce what is known as a panchromatic plate, which

[1] A micromillimetre or $\mu\mu$ = 1,000,000th part of a millimetre. Some writers express the wave-length in terms of Ångstrom Unit (A.U.), which is the ten-millionth part of a millimetre. Thus, 500 $\mu\mu$ may be written 5000 A.U. See Appendix, p. 285.

must be used for all methods of colour photography (excepting the two-plate method).

A plate dyed with eosin or erythrosin (and thereby rendered more sensitive to green and yellow rays) will

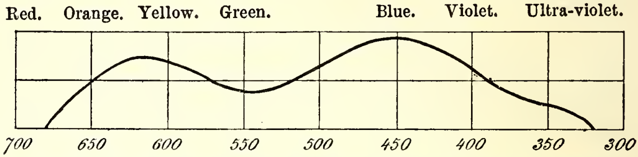


Fig. 10.—The Spectrum Curve of a Panchromatic Plate.

render colours sufficiently true to nature for ordinary purposes. Such a plate is termed iso-chromatic or ortho-chromatic (Fig. 11).

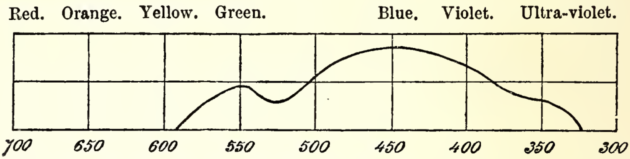


Fig. 11.—The Spectrum of an Isochromatic or Orthochromatic Plate.[1]

In order to render these two kinds of plates more effective, it is advisable to restrain the excessive action

[1] As it is rather difficult for the beginner to fix in his mind the numbers which correspond to the various colours, Dr. Mees, to whom photographers owe so much for his lucid pamphlets on this subject, has suggested an admirable mnemonic, which is as follows :—

The wave-lengths	for	Blue-violet	lie between	400 and 500 $\mu\mu$
,,	,,	Green	,,	500 and 600 $\mu\mu$
,,	,,	Red	,,	600 and 700 $\mu\mu$

of the blue-violet rays by the use of a yellow or green colour-filter. When these means are employed the curve of sensitivity of the plate will approximate more nearly to that of the human eye.

§ 25. **Purkinje Phenomenon.**—The intensity of a coloured light is largely the result of the admixture of mixed (or white) light with it, so that the more intense the coloured light, the whiter the colour becomes to the eye; and conversely, the feebler the light, the more does it approach black in shade. But this latter change is by no means equal for the three primary colours. If two different parts of the spectrum, say the blue and the red, be illuminated so that the brightness of each is the same, and then the common light is gradually reduced, the brightness of the two colours will no longer be equal. The long red waves become invisible much sooner than the blue-violet ones. As the light gets more and more feeble the spectrum becomes less and less visible towards the red end, so that the violet-blue and greenish-blue are the last colours to disappear, so that one can recognise objects of these colours by their bright shimmer or sheen, whereas the red, orange, and other colours appear dark purple, grey, or black. This change of colour is known as the Purkinje Phenomenon, from its discoverer. It shows us why the sky still appears blue in the twilight after all other colours have died away. If one goes into a picture gallery at dusk all the red and orange colours appear nearly black, while the blue colours, although "washed out," appear whitish and light in colour. If, on the other hand, the light be increased more and more, the reds and yellows will

become gradually more visible until they overstep the greens and blues, and ultimately become the brightest of all the colours.

Mr. T. E. Goodall has pointed out to me that a convolvulus growing on the western wall of a house is a rich blue in the morning, because it receives only diffused light, but, as the sun works round to the west, the colour ultimately attains a magenta-red just before the sun goes down.

The probable explanation of the Purkinje phenomenon lies in the nature of the rods and cones of the retina itself. As we have stated in § 19, the sensitive layer of the retina consists of an immense number of rods and cones packed together, so as to form a kind of mosaic when seen in cross-sections under the microscope. At the foveal pit (*i.e.* the centre of the macula) there are only cones, but the further one recedes from this spot the fewer are the cones, and the greater the number of rods. Now there are several ways of showing that the cones are most sensitive to the green, yellow, and orange rays (*i.e.* between $526\mu\mu$ and $566\mu\mu$), whereas the rods are most sensitive to the blue-green rays (round about $570\mu\mu$). When one fixes one's eyes on an object as in direct vision, it is the cones of the fovea which receive the sharp impression. This constitutes central vision, or *cone vision*. On the other hand, all surrounding objects not fixed with the eye, and which in consequence are only imperfectly seen, are observed by indirect vision, or *rod vision*, since it is the rods that greatly predominate. The following experiment will go far to prove the above statements.

First of all one must have a projection lantern fitted

with an arc light L, and a condenser C (Fig. 12). In front of this is a dispersing (negative) lens which renders the convergent rays parallel. The parallel beam then passes through the two Nicols N_1 and N_2. Then the light passes through a round opening in the

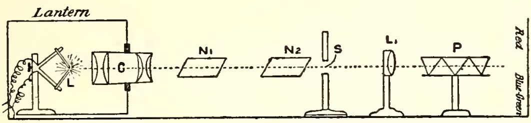


FIG. 12.

diaphragm S, and finally through the condensing lens L, and the direct spectroscope P. In this way a pure spectrum can be projected on to the screen Q. The upper half of the screen is covered with two sheets of red-coloured tissue paper, and the lower half with two sheets of blue-green paper of such tints that the red when illuminated is perceptibly brighter than the blue-green. If now one of the Nicols is rotated so that the light is gradually reduced, the blue-green field will become brighter than the red one, until at length the red field becomes invisible; while the blue-green field degenerates into a colourless whitish sheen. On covering the big sheet with black velvet and cutting a small square hole out of it in the centre (see Fig. 13) a small piece of the blue-green and red is to be seen through it. If now, while the Nicols are arranged so that the red is just a little brighter than the blue-green, and while one is gazing at the hole, a second person suddenly lifts off

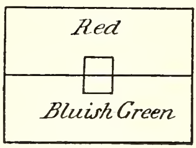


FIG. 13.

the black velvet sheet, the red sheet will appear quite black, while the white of the upper (blue-green) half of the sheet will appear quite colourless, but wonderfully bright and glistening like silver.

This effect applies to the photographic plate as well, for it will be found extremely difficult if not impossible to photograph reds, yellows, and yellow-greens in their natural colours in a dull light. This explains why such a disproportionately short exposure is necessary when photographing with colour plates in bright sunshine, and such a surprisingly long exposure (compared with the proportionate exposure for ordinary black and white pictures), when photographing with colour plates in a very dull light (see exposure table in the Appendix in proof of this).

CHAPTER V

METHODS OF OBTAINING PHOTOGRAPHS IN COLOUR

§ 26. **Lippmann's Interference Method.**—Among the various methods that have been tried to produce photographs having the natural colours of the original, none has excited more scientific interest than that of Prof. Lippmann, first shown in 1890, for no pigments of any kind are employed, but the colours are produced by the interference of light reflected by thin films. A very fine-grained, translucent plate is employed, which is placed, glass side towards the lens, in a special dark slide. This is filled with mercury, so as to form a mirror in contact with the film.

Let us suppose (Fig. 14) a series of parallel (plane) waves to be refracted through a lens on to such a plate in the camera. The waves will pass through the film and be reflected at the surface of the mirror.

These waves will, on their return, engender a number of stationary waves, owing to their neutralising the opposing waves. Consider a point P in the film, which is at a distance x from the mirror. Then the waves about to proceed to O from P will encounter the waves which have been to and are returning from O, so that at P we have two sets of waves, the direct waves and the reflected waves. They both started in the same

phase at P, but the reflected waves have travelled a distance equal to $2x$ further. Moreover, on reaching the mirror, they are found to differ in phase by half a wave-length, because the reflection took place at the surface of the denser medium, and, by a well-known

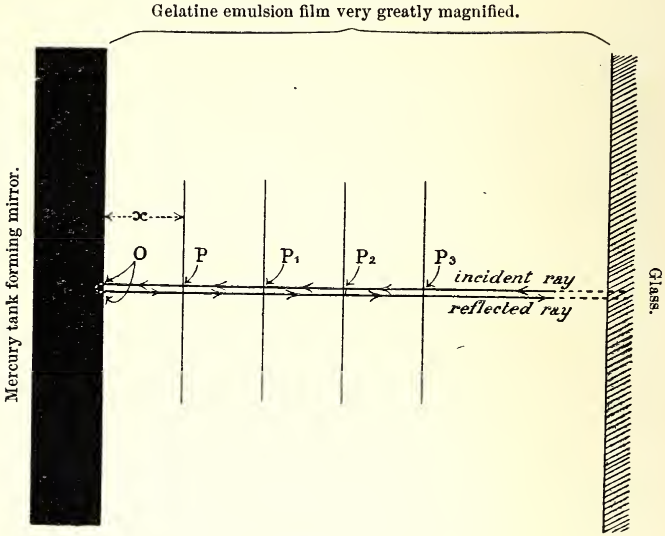
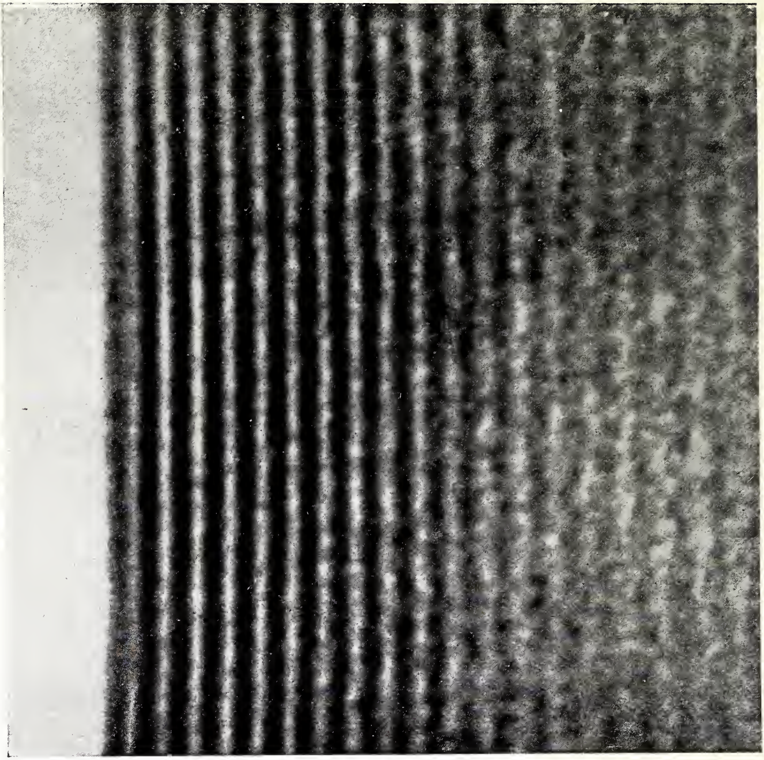


Fig. 14.

law, reflection at the surface of a denser medium causes a retardation $= \lambda/2$ in the wave.

Hence the path traversed by the returning wave $= 2x + \lambda/2$. Now this must be an odd number of half-wave lengths, provided that PO $= n\lambda/2$, n being an even number, since we have the extra $\lambda/2$ to make the total an odd one. If this is so, there will be



$Px\ P_1x\ P_2x$

[*Copyright.*

Section of a Lippmann Photographic Film, made through the red end of the spectrum of arc light (× 11,000). Prepared and photographed by Edgar Senior, Esq., and reproduced here by his permission. Zeiss' Apoch. Obj. 3 mm. Oc. 2; yellow screen. The dark deposits of silver P, P_1, P_2, etc., occur at half wave-length intervals x, x, x.

To face p. 65.

interference throughout the planes P and P_1, because P_1 is separated by the distance x from P, and so for the other planes P_2, P_3, etc., throughout the film. The distance between these planes is equal to half a given wave-length of light for a definite line of the spectrum, so that these planes will vary for each colour, being closer together towards the violet end, and wider towards the red. Wherever the reflected wave meets an incident wave in the opposite phase, the trough of the wave will be filled up, so there will be a calm region, and it will have no effect on the silver bromide at that spot; but where it meets its opponent in the same phase, the wave will be intensified and have a strong action on the silver bromide particles. If, therefore, the plate is developed and fixed, there will be a series of planes of darkened silver particles at regular intervals, the width being in strict proportion to the length of the wave, while in between these will be other planes corresponding to other parts of the spectrum. Dr. Neuhaus first succeeded in stripping off a piece of such a film, and making very thin sections, which, when highly magnified, showed an appearance similar to Plate V.

The dark lines are due to the reduced silver particles, the bright lines to planes where no action occurred. If, therefore, the film, when fixed and dried, be turned so that the eye sees the film at or near the angle of reflection,[1] the colours corresponding to those of the

[1] The angle of reflection is the angle which the reflected ray makes with a perpendicular line drawn from the surface at the point of impact. It is in the same plane with, and equal to the angle made by, the incident ray with the normal (perpendicular line) above mentioned.

F

original object photographed will be distinctly perceived. By fixing a shallow-angled prism behind the plate surface reflections will be got rid of, and the colours will be brought out much more vividly. In this way, not only can the solar spectrum be reproduced, but, under favourable circumstances, landscapes, flowers, butterflies, and other brightly coloured objects may be photographed. Many of the old Daguerreotypes showed traces of the natural colours, as can be seen in specimens at the present day if observed at the proper angle, since the polished silver backing takes the place of the mercury trough, but it remained for Zenker and Lippmann to give the correct explanation of the phenomenon.

Colours produced by interference were observed as far back as Sir Isaac Newton, who described them as occurring when two glass plates are separated by a very thin film of liquid or air. Thus, if a slightly convex surface of glass be placed on a perfectly flat surface, the thin film around the point of contact will give rise to coloured circles, which are known as Newton's rings. By measuring the diameters of the rings, the curvature of the glass may be calculated, or, knowing the curvature, the thickness of the film can be found, and if monochromatic light be used, its wavelength may be calculated also. The colours in the plumage of many butterflies and birds and the bodies of beetles, as well as the exquisite tints of mother-of-pearl and the soap-bubble, are due to interference phenomena and not to actual pigments. This may be seen by regarding these structures at different angles, when the colours will be seen to vary. A still more familiar example may be observed when tar or petrol

is spilled and spreads over the road, especially if it is wet, so that the liquid expands in a thin film over the water.

§ 27. **Theory of Colour Formation.**—If we project transparencies from a set of three-colour negatives on to a screen by means of three lanterns, we must place in front of each lantern slide a coloured glass similar to that used for the corresponding negative, *i.e.* we must illuminate the transparency from the red filter negative with red light, the green with green light, and the blue with blue light, but when we superpose the transparent prints, made from each of the negatives, we must first colour each of these prints not in the colours used for their respective filters, but in the complementary colours to these, *i.e.* in colours which transmit the other two colours which, added to the filter, made up white light. Thus the negative taken through the red filter is printed in a colour transmitting green and blue, these being the other two colours which, with red, form white light. This colour is cyan-blue, the complementary colour to red. It is, moreover, a light greenish-blue, quite different from spectrum deep blue. The green filter negative is printed in the complementary colour to green, viz. a magenta-pink, and the blue filter negative is printed in the complementary colour to blue, viz. canary-coloured yellow.

The reason is as follows:—In the former case discs of red, green, and blue lights are overlapped, so that coloured lights are added to coloured lights (additive method), but in superposing one print over another we are adding not lights to lights, but opacities to opacities,

since each additional print abstracts part of the light transmitted by the first one. Thus, if one paints a patch of red pigment on a piece of white paper the latter reflects light of all colours and consequently appears white, but the patch of red pigment absorbs the green and blue and only reflects the red light, and therefore the patch appears darker than the white. If we now paint a patch of green and another of blue over the red patch, the latter will appear black and not white, whereas if light is transmitted through transparent discs of three primary colours in their correct proportions and superposed on a screen, the result will be a white disc. Fig. 15 represents the additive effect of overlapping the coloured discs of red, green, and blue lights, the result being a white, or nearly white patch on the screen, whereas Fig. 16 represents the subtractive

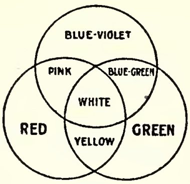


Fig. 15.—Diagram showing the effects of additive lights.

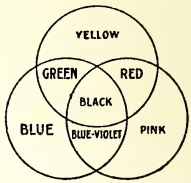
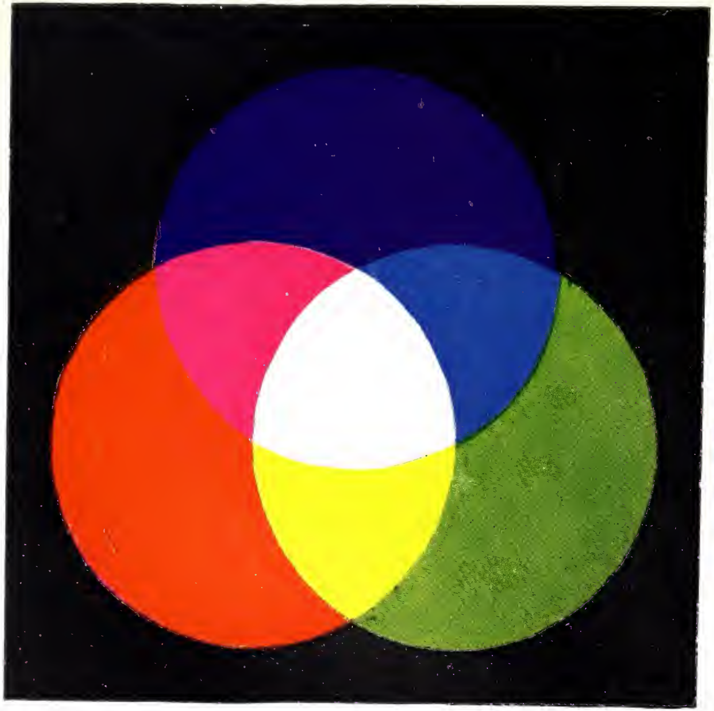


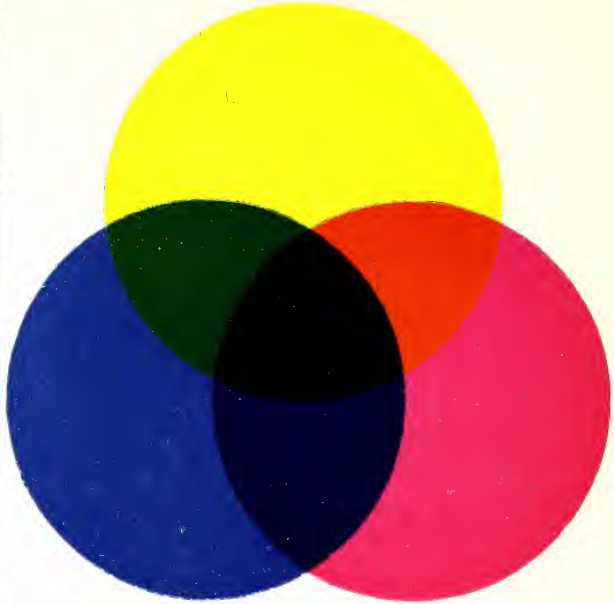
Fig. 16.—Diagram showing the effects of subtractive colours.

effect of superimposing discs of gelatine films or glass stained with the complementary colours to red, green, and blue, the result being a black patch. The coloured illustration (Plate VI.) shows the effect of the superposition of the colours, to which the above figures furnish the key.

PLATE VI.



Primary colours. Diagram, showing the effect of superposition of "Additive" *Lights*, as explained on p. 68.



Primary colours. Diagram showing the effect of superposition of "Subtractive" *Colours*, as explained on p. 68.

To face p. 68.

In order to make a three-colour transparency, we must therefore proceed as follows:—A red filter negative is taken and a contact transparency made by exposing a plate behind the negative, and developed in the usual way; the grey-black image of reduced silver is now replaced by ferrocyanide of iron, the metallic silver deposit acting as a mordant, the result being a greenish-blue colour, which fortunately happens to be the exact complementary colour of the red filter. Two thin transparent celluloid films are now coated with a soluble gelatine film containing a trace of bromide of silver and sensitized like carbon tissue with bichromate of potash. This renders the parts affected by the light insoluble in water. One of these is now placed celluloid side down in contact with the green filter negative, and after the details of the image are quite visible the exposure is stopped. The film is then washed in warm water to remove all the unaffected gelatine, fixed in "hypo," washed and dried. It is then dipped in a crimson-pink dye bath, so as to get a pink print, the complement of the green filter. Lastly, we obtain a print of the blue filter negative with the remaining film celluloid side down, and, after treatment in the same way, it is stained a bright yellow, which is the complementary colour of the blue; when these two prints are dry they are mounted together in correct register. The pink print is cemented on to the greenish-blue transparency, and the yellow print on the top of all, the films being placed *face downwards*. This is necessary, since the greenish-blue print on the glass is a direct print made by placing the sensitive side in contact with the film side of the negative,

whereas the two celluloid films are printed through the back by placing the celluloid side next to the film of the negative, and both are turned round on finally placing them together. This not only secures the prints being all turned the right way, but the two most important components, viz. the greenish-blue and pink are mounted in actual contact, while the third (yellow) print is only separated by the thickness of one film of celluloid, which does not affect the results. The three pictures are then mounted behind glass and used as a lantern slide, or framed and hung in a window. If the proper values have been given to the colours, the final result, whether seen on the screen or examined by reflected light, is strikingly effective and realistic.

The difficulties attendant on three-colour photography, and especially on making all three exposures at one time and of equal gradation has led to attempts being made with two colours. Gurtner has invented and patented a very simple process, which, while ignoring the red element, still enables one to produce pictures of natural scenery.[1]

[1] See § 83, pp. 152–153.

CHAPTER VI

SINGLE-PLATE COLOUR PROCESSES

§ 28. **Joly's Ruled-Line Screen Process.**—This is essentially a three-colour process, invented by Professor Joly of Dublin, in 1897, but which for various reasons has not been taken up commercially. The method is as follows :—

A glass plate is ruled with a series of orange, blue-green, and blue lines, about $\frac{1}{250}$ in. apart, and repeated in the above order across the plate. This triple-coloured glass is placed just in front of a sensitized plate, and a photograph of a coloured object is taken in the camera and developed. The negative may therefore be considered as composed of three parts, each corresponding to its particular line. A transparency is now made by contact, and another plate, ruled with the same number of lines, is placed in contact with it, only, instead of the coloured lines being orange, blue-green and blue, they are now ruled red, green, and blue-violet, thus corresponding to the three-colour sensations. The red lines are adjusted to fall on the image formed behind the orange lines, the green on the blue-green, and the blue-violet on the image formed behind the blue image. It is of prime

importance that the lines are in exact register, otherwise the whole aspect of the picture will be changed. Therefore the lines on the negative which were behind the orange lines of the screen, must, when viewed through the positive transparency, be exactly in register with the red lines of the second screen, and so for the other two colours.

The positive and second screen can be placed in register, and thrown on to a sheet by an optical lantern, and a facsimile in colours of the original object may be seen by an audience on the sheet. It is necessary that the sheet should be at some distance from the audience, otherwise the lines, being highly magnified, would be seen. At a little distance away the lines blend, and a remarkably faithful and brilliant image is seen. If such a slide be placed in front of a window the colours can still be seen, but they vary according to whether the slide is looked at in front or from either side. Thus the colours of a dress may appear of a rose colour when observed obliquely from the right-hand side, but a greenish-blue when seen from the left side of the picture. This is due to the fact that the positive and second screen have their corresponding lines in register when seen from the front, but when looked at obliquely, parallax is set up, so that on the one side the blue-green lines predominate, while on the other side the red are most seen. Since the red and green lines together produce yellow or orange, the green and blue-violet, blue, and the blue-violet and red, crimson, it will be seen that all shades of colour can be reproduced, although the mixing of lights and the mixing of pigments will not produce the same results.

§ 29. **Comparison between the Various Screen Plates.**—We may divide all the single-plate colour processes into three classes according to the nature of the colour-screen. It is unnecessary to describe the methods of manufacture as they are extremely complicated, and what the reader really wants to know is how the various screens affect the appearance of the picture. All the screens, however, have one feature in common: they all consist of a pattern composed of the three primary colours, red, green, and blue-violet, which transmit their respective coloured lights. By drawing up a table we can best review all the screen plates that have so far appeared, omitting only those that have been abandoned.

It will be seen from the accompanying table that the plates in Class I. are distinguished from those in Classes II. and III. by being "regular" in texture, whereas the latter are "irregular."

A "regular" plate is one which is ruled or impressed with a regular series of discs, lines, or squares, of which the Paget and Omnicolore are good examples.

An "irregular" plate is one in which the coloured particles are strewn haphazard over the plate. The Autochrome is the best known example of this class.

The "regular" plates all possess extreme softness and brilliancy of colouring. The colours are very rich and vivid, and produce a woven silk-like appearance due to the symmetry of the pattern. If a suitable subject be selected and the plate correctly exposed and developed, the result is remarkably fine, and cannot be excelled (if equalled) by any other kind of plate. On the other hand, the range of colours, and especially the

Table giving the Characteristic Features of the Principal Single-Plate Colour Screens.

Method of formation of colour screen.	Name of plate.	Apparent colour of screen.	Width of lines, rectangles, or dots, inches (mm.).	Presence of visible spectra when viewed as transparency.
Class I.—**By regular rulings or**	**printings of fine**	**parallel lines,**	**dots, or rectangles.**	
(*a*) Fine parallel red, green, and blue lines	Warner-Powrie I. "Florence" (Fig. 16)	Pale grey-green	$\frac{1}{600}$ in. (0·043 mm.)	Very marked (especially green and purple) even by daylight.
(*b*) Blue lines alternating with red and green rectangles	Jougla's "Omnicolore" (Fig. 14)	Decided pink	B $\frac{1}{500}$ in. (0·05 mm.) G $\frac{1}{330} \times \frac{1}{420}$ (0·08 × 0·06) R $\frac{1}{420} \times \frac{1}{600}$ (0·06 × 0·04)	Very marked by incandescent light, not noticed in daylight.
Ditto	Lumière line screen	Nearly neutral	$\frac{1}{420}$ (0·06) (?)	(?)
(*c*) Green lines alternating with red and blue rectangles	Dufay (Fig. 20) "Dioptichrome"	Neutral	G $\frac{1}{420}$ (0·06) B $\frac{1}{400} \times \frac{1}{280}$ (0·063×0·09) R $\frac{1}{350} \times \frac{1}{250}$ (0·07 × 0·1)	None or very slight only.
(*d*) Red, green, and blue-violet squares and rectangles	Paget colour plate	Faint greenish indigo	G $\frac{1}{400}$ in. (0·063) R $\frac{1}{400}$ in. (0·063) B $\frac{1}{400} \times \frac{1}{800}$ (0·063×0·032)	(Faint trace only).
Class II. — **Screens made by**	**strewing plate with**	**irregular grains,**	**etc.**	
Starch grains, dyed red, green, and blue-violet	(Fig. 15) Lumière's "Autochrome"	Faint pink	Grains average $\frac{1}{1200}$ in. to $\frac{1}{2500}$ in. (0·021 to 0·01)	No trace.
Class III.—**By compressing sheets**	**of cemented gela-**	**tine and cutting**	**when softened with a**	**microtome.**
(*a*) Cut horizontally	Krayn line	Ditto	(?)	Slight spectra.
(*b*) Same, but cut vertically and horizontally	Krayn mosaic (Fig. 21)	Ditto	$\frac{1}{800}$ in. (0·031 mm.)	None.

tones and shades, are more restricted, and the colours less true to nature than in the case of an Autochrome similarly treated. This is partly due to the fact that all "regular" plates partake more or less of the nature of a diffraction grating, and are liable to give rise to imperfectly formed and impure spectra which interfere seriously with the general appearance of the picture. The conspicuousness of these spectra is in direct proportion to the fineness of the rulings. (As discs do not, like rulings, give rise to spectra, the Thames plate is free from this defect.) Another drawback is that the colours tend to change into their complementaries or into mixtures of one or more of the adjacent colours when the picture is viewed sideways. This is owing to parallax, and is specially noticeable in those plates in which the screen is separated from the sensitive film.

§ 30. **Parallax**—may be defined as the displacement of one object with respect to another when viewed from different positions. If, for example, you place a red, a green and a blue marble to represent the three coloured discs side by side on the table at right angles to the line of view, and put a white marble a couple of inches in front of the centre (green) one and then look along the table at it a couple of feet away, the white marble will hide the green one. If you move a little to the right it will hide the red one. If you move to the left it will hide the blue marble. This is due to parallax, and the amount of parallax increases directly with the distance between the two planes. It is this parallactic displacement which enables astronomers to measure approximately the distance of some of the stars, when the earth is first at one end and six months afterwards

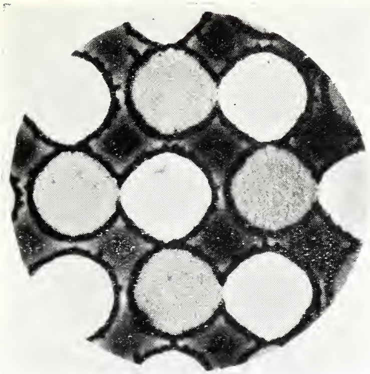
at the other end of its elliptical orbit as it travels round the sun.

The Autochrome plate gives rise to a purer and wider range of colours. As the film is very thin there is no parallax, and, like all other "irregular plates," cannot give rise to diffraction spectra even when the transparency is illuminated by the arc or clear bulb electric light. The grain is so fine that complex colours such as white, greys, gold, silver, flesh, ivory, shagreen, etc., can be very faithfully reproduced, and these most of the "regular" plates fail in rendering properly.

§ 31. **Jougla's "Omnicolore" Plate.**—The colour-screen consists of a series of parallel blue rulings or stripes, the intervening spaces being filled by green colour surrounding red squares (Plate VII.). The breadth of the blue stripes = 0·04 mm. The breadth of the green spaces 0·07 mm., and that of each red square 0·05 mm. Hence, if we divide up the blue stripes into as many areas as there are red squares or green intervals, we shall find the ratio of the red, green, and blue areas to be as 3 : 4 : 5, the blue areas being nearly twice the size of the red ones, and the green intermediate between the two. The relative sizes correspond to the apparent brightness of each of these colours to the eye. This difference is only apparent, as it is corrected by the filter, which is of a light canary yellow colour, and is slightly more rapid than the Autochrome one. The film is tough.

§ 32. **Dufay's "Dioptichrome" Plate** closely resembles the Omnicolore both in appearance, method of developing, and in results. The "First black condition" (see § 25, p. 59) is very perfectly fulfilled. The

PLATE VII.



"Thames" Screen × 100.

"Omnicolore" Screen × 100.

To face p. 76.

colours are therefore remarkably true to nature. The colour-screen consists of a series of parallel green rulings, the intervening spaces being filled by alternating red and blue squares (Plate VIII.). The breadth of the green stripes = 0·06 mm. That of the blue squares = 0·06 mm., and the red 0·07 mm. Like the Omnicolore and Thames, the colours, if strong and vivid, have a charmingly artistic texture as if painted on woven silk. The plates are said to be more rapid[1] than the Autochrome in the proportion of 5″ to $6\frac{1}{2}$ (see § 39), and the film will bear rougher handling than the Autochrome, but less than the Omnicolore or Thames plates. The colour filters of the Omnicolore and Dufay are practically the same, and therefore interchangeable, but they will not be correct for either the Autochrome or Thames plates, the former having a pinker tint and the latter a pale yellow one. The positive, owing to its great transparency, is admirably suited to lantern projection.

§ 33. **Thames Screen Plate.**—This plate, invented and made in London by the Thames Colour Plate Company, has a screen impressed with rows of alternating red and green circular discs. The interstices are filled in with a violet-blue dye, so that the entire plate is covered with the three colours, and presents no blank spaces. See Plate VII.

The colour-filter is a pale canary yellow. Since the colours are much more transparent than the starch cells of the Autochrome plate, the rapidity is correspondingly increased. Also a lighter colour-filter being used, shutter exposures as short as $\frac{1}{20}$ sec. can be made

[1] According to the author's experience they are somewhat less rapid (see Appendix table).

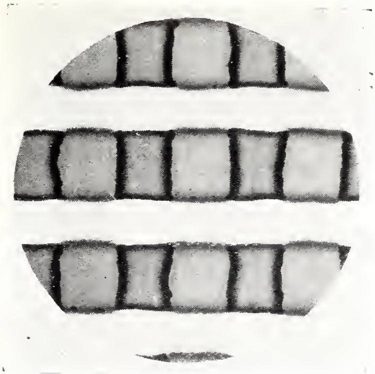
under favourable conditions with a stop of F/5·6, whereby objects in motion can be photographed.

§ 34. **Combined and Separate Screen Plates compared.**—The Thames Colour Plate Co.[1] issue plates of both kinds, and each has its advocates. The *combined* plate in which the sensitive film is permanently attached to the screen is easier to work, as the positive is obtained direct by immersion into a dissolving agent such as acid bichromate. Trouble from parallax, etc., as described above, does not arise in the combined plate.

The *separate* method (*i.e.* one in which the colour-screen is on a separate glass from the panchromatic film) is perhaps a little more complicated in the working, since after taking the negative a positive must be made from it, and carefully adjusted to a screen. The registration of the latter requires a considerable amount of care to perform correctly. Owing to the slight separation of the screen and film, parallax readily appears; nevertheless the separate method has many points in its favour. If the negative is defective we may substitute another panchromatic plate and make a second exposure at a very much smaller cost. Also we may use the negative to print off on P.O.P. any number of copies, and further, as the screen causes the entire picture to be broken up by its almost invisible pattern, the prints possess a peculiar charm of their own. Enlargements in monochrome may be made from them, or they can be reproduced in

[1] This company no longer issues plates. But an improved plate is now sold by the Paget Prize Plate Co., Ltd. (see Paget plate).

PLATE VIII.



" Dioptichrome " Screen × 100.

" Krayn " Screen × 100.

To face p. 78.

colour, as will be described later. It is obvious that "irregular" plates can never be worked by the separate method, as it is impossible to readjust the positive and screen into register again. In the separate method one can always use the negative for printing purposes in the same way as any other negative, and then make a transparency on a slow process or lantern plate for the purpose of binding up with a screen for a colour transparency. As the screens are exactly alike any one of them may be used. The uncombined or "separate plates" are twice as rapid as the combined ones. In both cases the films will stand fairly rough usage compared with the Autochrome.

Quite recently a method of getting rid of all parallax has been devised by the makers of the Thames plate. Instead of making a positive transparency and binding it up in register with a colour-screen, they coat the colour-screen with a transparent (and consequently extremely thin) and very slow emulsion—in other words, a lantern-slide emulsion. One of these is placed film to film with the original negative and carefully registered by candle-light in the dark room, a ground glass being placed in front of the candle to distribute the light. *The registration must be made in the complementary colours of the subject, e.g.* yellow flowers must be registered as blue, and green leaves as red, etc. An exposure is then made to strong light and the colour-screen plate developed and fixed in the ordinary manner. In this way picture and screen are combined in a single transparency. These coated colour-screens are about to be placed on the market by the Company.

§ 35. **Paget Plate.**—This make of colour-plate is

produced exactly on the same lines as the Thames plate already described, in fact it is merely an improvement on the latter, and like it is issued in two forms, the separate and the combined plate.

In the former case the panchromatic sensitive plate and the colour-screen are issued separately and are placed with their films in contact in the dark slide as tightly as possible, so that the two films have nowhere any air space between them, otherwise parallax will be set up and the result will not be satisfactory. For this purpose a hinged back is the best, and care should be taken that the spring which holds the plate down is a strong one. The glass side of the colour-screen must, of course, be placed facing the lens. After exposure, the plate is developed in the ordinary way, fixed, and dried, and a positive made from it in a printing-frame, having the glass side of the screen facing the light exactly as in the former case. After development, fixing, and drying, the positive is adjusted carefully behind a viewing colour-screen and bound up like a lantern slide.

The other form of plate has the screen coated with a panchromatic emulsion in the same way as an Autochrome or Dufay plate.

The chief differences between the Paget and the Thames plates are; (1st), the screen is formed of small coloured squares instead of circles which are slightly smaller than the latter, being each about $\frac{1}{300}$ inch in diameter instead of $\frac{1}{220}$ inch. (2nd) Two screens are employed, one for taking the negative (taking-screen), the other for binding up with the positive copy (viewing screen). These two screens are identical, save that the

colours of the squares are not quite the same. The taking-screen is of a pale indigo colour, with a faint trace of green, the other also a pale indigo, but inclining very slightly towards a brown shade. But they are very nearly alike.

The filter used is cut from a thin sheet of gelatine stained with Aurantia, or some such yellow dye. In cutting out a disc to place between the lenses of the combination it is advisable to cut it out with a pair of scissors, holding the gelatine between two pieces of paper in order to prevent the fingers from marking it, as the gelatine is very easily smeared by the fingers, and the marks cannot be removed afterwards. If the inner flange of the lens be pressed on a piece of paper, it is quite easy to cut round inside the ring so formed with a pair of scissors.

The exposure (see Tables) is about $\frac{1}{4}$th or $\frac{1}{5}$th that of a Lumière Autochrome, and corresponds to 15 Watkins speed number; or F24 Wynne, with plate-screen in position. For an open landscape in good light at F/8, $\frac{1}{4}$ second exposure is enough. For an open-air portrait (entire figure) in sunlight, 1 second with F/8, or 3 seconds with head and shoulders only, in diffused light.

As there is a dip in the spectrum-curve of the plate, viz. in the region of the green, a developing-lamp may be used if the light be screened by three sheets of yellow and three of green Virida paper as for other single colour-plates, but on no account must a RED light be used.

§ 36. **Development.**—Any developer which gives rich black tones may be employed, but the makers

recommend 1 : 30 Rodinal. Development should be complete in two minutes. It is advisable to cover the dish over with a card during development, only exposing the plate to the light for a second (or less) after the expiration of 15 seconds from pouring on the developer, so as to know the instant the picture begins to appear. Once this is recognised, the time can be multiplied by the factor-number, and the development completed in darkness. The great point is to obtain a clean, brilliant (plucky) negative entirely free from fog, and with clear shadows. Otherwise a dull positive will result, and weak or disappointing colour-effects when the positive is bound up with the viewing-screen.

When the negative is dried, a transparency copy is made by contact in a printing-frame with any Ordinary plate. The Paget Company issue a special fine-grain slow plate for the purpose, which has a very thin film similar to that of a lantern plate. This is developed in the ordinary way, using a red light. A developer which gives a dense black image is the best. For this purpose Metol or Metol-hydroquinone is recommended. The exposure averages about 15 seconds with an ordinary candle at 1 foot, or 5 seconds with a 16 candlepower electric light at 3 feet.

It is best to use a hinge double back to hold the two plates, since there is more room than in the case of a solid slide; and, besides this, the metal division is furnished with a spring which presses the plates together. If the slides have a very shallow rebate, or if metal sheaths are used to hold the plates, it is necessary to procure extra thin taking-screens. These

can now be obtained from the Paget Company in the place of the thick ones.

The essential point is to get absolute contact between the two plates, and for this reason a strong spring to press them together is a *sine qua non*. *If they are not firmly squeezed together you will hardly get any colour at all in the finished picture.*

The makers do not recommend either intensification or reduction of the negative, so that any modification in the density must be effected by altering the exposure or development of the positive.

For fixing, use hypo 6 oz., metabisulphate of potash ½ oz., and water 20 oz.

When finally binding up the positives a sheet of fine-ground glass is recommended. Some transparencies, however, are better without it. When the viewing-screen is placed behind the transparency, a coloured moiré pattern will be noticed. As the screen is shifted, this pattern will be seen to grow larger and larger, until it finally disappears. This is the moment when the colours are correct.

Notwithstanding all that has been written to the contrary, there can be no doubt that combined plates are much easier to work, and give more satisfactory results than the separate method. Moreover, they give richer colours with more body, and run no risk of getting out of register, a fault which is very difficult to adjust afterwards.

On the other hand, it cannot be denied that the separate plates possess three distinct points in their favour. (1) They are three times as rapid as a Lumière plate, which fact allows of a moving object being taken

with full aperture. (2) Being very transparent, they are specially suitable for lantern projection. (3) Any number of copies can be taken by making fresh transparency copies and binding them up with new viewing-screens.

§ 37. **Combined Paget Plate.**[1]—This requires no special description. It is exposed and developed precisely in the same way as an Autochrome or Dufay plate, the picture being reversed in an acid bichromate solution afterwards, and then redeveloped in full daylight (see instructions for developing Autochrome plates).

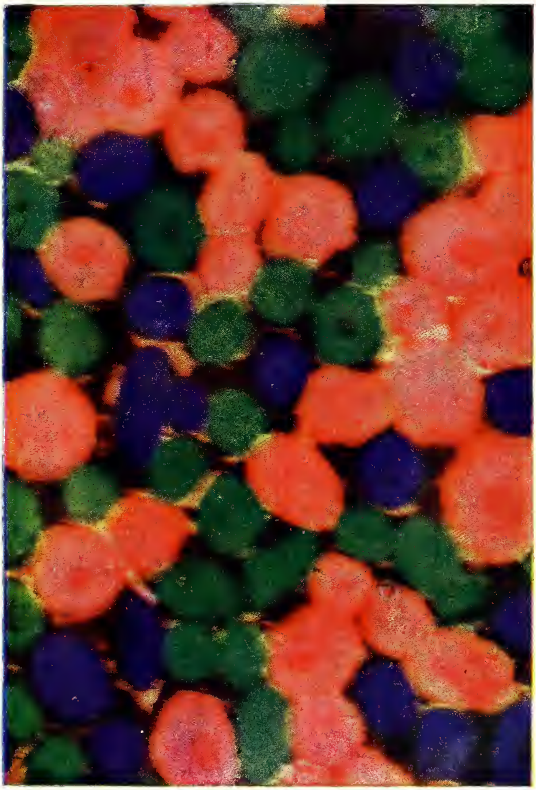
As the grating is broken up by the ruling which forms microscopic squares, the spectra are barely perceptible even with artificial light.

§ 38. **The Lumière "Autochrome" Plate.**—This beautiful process, patented by A. Lumière et Fils of Lyons in 1904, depends on a colour-screen built up of starch grains dyed with the three primary colours, red, green, and blue-violet, and overlaid with a thin panchromatic sensitized film. The grains are of ordinary potato starch, varying between 0·01 and 0·02 mm. The smallest cells are about the size of a white blood-corpuscle, so that the grains are just within the limit of perception. There are about four million grains per square inch. When an Autochrome slide is projected on to a lantern sheet the coloured grains are invisible to the audience a few yards away (see Plates IX. and X.).

After dyeing, the starch cells are mixed together very intimately (so as to avoid "clumping") in the proportion

[1] This plate is not yet on the market (November, 1915).

PLATE IX.



Dyed-starch-grain Filter. Three-colour print, copied from a Lumière Autochrome plate, showing the dyed grains; magnified 700 diameters.

To face p. 84.

of four green to three red and two blue. The layer of cells is flattened by rollers to fill up the interstices, and then varnished. Since the three colours combine to give the effect of white to the eye, an Autochrome plate should resemble an ordinary dry plate. As a matter of fact, the screen has a pale salmon-pink colour when held up to the light.

§ 39. **Relative Speeds.**—The following table by Mees and Pledge gives the relative speeds of emulsion and screens, and the exposure speeds behind their respective filters for the respective plates:—

	Autochrome.	Paget.	Omnicolore.	Dufay.
Emulsion speed (Watkins)	35	120	22	13
Screen factor ,, .	12	8	7	5
Filter factor ,, .	2	$1\frac{1}{2}$	$1\frac{1}{4}$	$1\frac{1}{2}$
Effective speed ,, .	$1\frac{1}{2}$	$4\frac{1}{2}$	$2\frac{1}{2}$	2

so that if the Paget plate requires 1 sec. exposure, the Autochrome requires about 3 secs., the Omnicolore plate 2 secs., and the Dufay a little less.

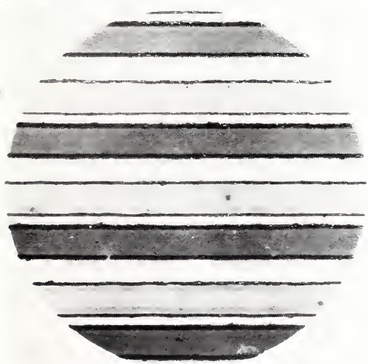
CHAPTER VII

SINGLE-PLATE PROCESSES DIAGRAMMATICALLY EXPLAINED

§ 40. **Von Hübl's Diagram.**—As some readers can understand the subject better by means of a diagram than by words alone, Fig. 26, reproduced from a diagram by Von Hübl, shows in diagrammatic section the action of light passing through the glass and falling on the three-colour layer of the screen plate. This diagram may be applied when considering the case of any of the classes of colour-screen plates, which, though differing in construction, are all identical in principle. They all agree in having lines, patches, or spots of red, green, and blue in more or less equal proportions over the entire plate (r. gr. bl., Fig. 17). If such a plate is now exposed in a camera, with the glass side turned towards a coloured object, we shall obtain the following result: A cinnabar red object which absorbs green and blue will only emit red rays; these will pass through the red elements of the screen, and will act on the particles of silver bromide behind them, and the film at that spot will become blackened in the course of development. The red rays will be absorbed by the green and blue elements of the screen, and so no change will be seen in the film behind them. If the plate be now developed

PLATE X.

"Autochrome" Screen × 100.



"Warner Powrie" Screen × 100.

To face p. 86.

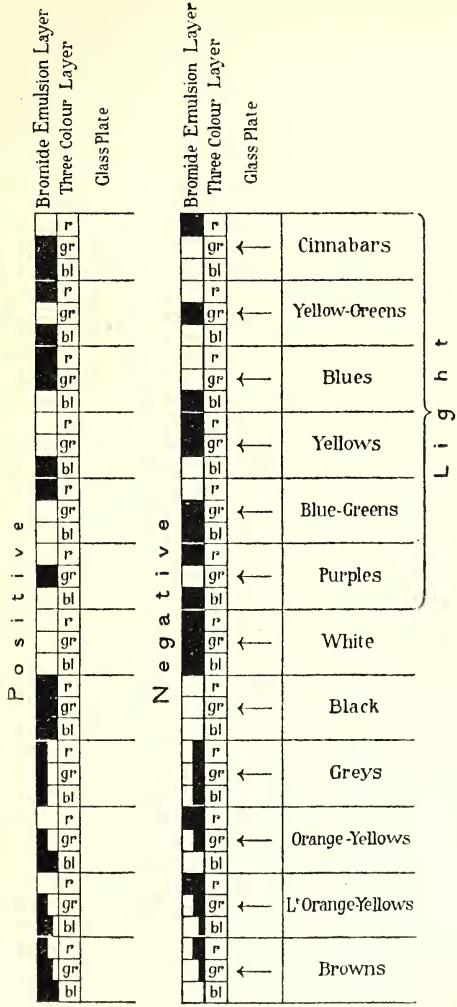

Bromide Emulsion Layer
Three Colour Layer
Glass Plate
Positive
Bromide Emulsion Layer
Three Colour Layer
Glass Plate
Negative
r
gr
bl
Cinnabars
Yellow-Greens
Blues
Yellows
Blue-Greens
Purples
White
Black
Greys
Orange-Yellows
L^t Orange-Yellows
Browns
Light

FIG. 17.

and fixed we shall find all the red elements covered with blackened silver, but the blue and green ones will be transparent, and seen together will give rise to a bluish-green colour (see right-hand diagram). If the object is green, the rays will be absorbed by the red and blue elements, and the film behind the green elements will become blackened, so that after development and fixation the plate will show a purple-red colour. In the same way, a yellow object (which appears yellow because it absorbs all the blue rays) emits green and red rays, and these will be absorbed by the blue elements and will pass through the red and green ones. The result will be that the silver behind the red and green elements will be blackened by the developer, and the plate will appear blue at that spot. If the object is a brown one (see bottom space), it will emit a large number of red rays, a small number of green rays, and hardly any blue at all, so that the red elements will allow about half the light to go through, the green about a quarter, and the blue perhaps an eighth. After development and fixing, the film behind the red elements will appear dark grey, that behind the green elements a light grey, and that behind the blue hardly changed at all, with the result that after development and fixing, the negative will show a grey yellowish-green colour. The fixed negative, therefore, will always appear in the complementary colour to the objects photographed. If after development but without fixing the negative be placed in a bath of acid permanganate of potash, or acid bichromate of soda, the whole of the blackened silver deposit is dissolved away. If now the plate is exposed to daylight

and redeveloped, the whole of the silver bromide which has not been acted on originally, will be reduced to blackened silver, so that the image will now be reversed, and all those parts which were blackened during the first development will be now more or less transparent. In this way the picture will appear in the colours of the objects photographed. This can be readily seen by comparing the right and left diagrams of Fig. 17. A black object will reflect hardly any light, so that the developed negative will be nearly transparent in the region of the image if the plate is fixed. If it is not fixed but exposed to light and redeveloped, then all the bromide of silver will be reduced to blackened silver, and the positive will show a black image. If, on the other hand, a white object is photographed, the light will pass through all three colours, red, green, and blue, with the result that the image will appear quite black on development. In the reversal bath this image will be nearly completely dissolved, so that on redeveloping there will be next to nothing left to develop, and the image will appear white. In fact, we may say generally that after the second development there is nothing left to fix in the hypo.

§ 41. **The First Black Condition.**—McDonough has stated that the perfect screen plate is one in which the colours are so perfectly balanced that when viewed as a transparency it is entirely free from colour. This he calls the first black condition. There is no plate which entirely comes up to this standard, but the Dufay and the Lumière line screens are practically neutral, while the Paget is a pale greenish-indigo.

Some varieties of colour plates fall lamentably below this standard, and cannot even reproduce the spectrum colours so that they can be recognised. Such plates are worse than useless, and tend to bring the art into discredit.

§ 42. **The Second Black Condition.**—If the first condition be fulfilled, it is further necessary, in order to produce a perfectly compensated plate, that it should comply with the second black condition, viz. that the colour-filter should have such power of absorption that when a grey object is photographed an identical silver deposit should be produced behind each of the three coloured elements. Several makes of plates are satisfactory in this respect.

§ 43. **How the Appearance of White is produced on an Autochrome Colour-Plate.**—It may be observed by any one that if a piece of sensitive film be stripped off a colour-plate leaving the coloured starch-grains on the plate, and the latter be held up to the light and examined, the stripped portion does not appear white (as one would expect) owing to the combined sensation produced by the three primary colours; but, instead, a pale pink, grey, or greenish tint is seen. Why, then, does a snow-mountain, a white shirt-front, or a collar, come out a pure white in the transparency? The reason appears to be as follows:—If an Autochrome positive be examined under a high-power microscope, and if the grains be carefully focussed up, they will be seen as perfectly clear grains wherever a white object has left its image on the positive.

If, now, the objective be very gently racked away

from the grains by means of the fine adjustment, an immense number of very fine black reduced silver particles will be seen covering the field. It is this veil of fine pigment particles which causes the sensation of white, and the finer the silver particles, and the more evenly distributed they are, the whiter will the image appear. This interesting discovery was first made by Professor A. Forster, of Berne, in 1910. There can be no doubt that this is the cause of the impression of white to the eye. The professor ascribes the white appearance to the black particles forming a grating (Raster), but after a careful examination of a great number of specimens under the microscope, the writer came to the conclusion that a grating cannot possibly be formed by these pigment particles, and the action of the particles in producing the sensation of white light requires some other explanation. This the writer has attempted to do as follows: if we take a plate from which the gelatine layer has been stripped off, we shall find that the light passes through the red, green, and blue starch grains in the form of train waves having regular periods. When, however, the light of a white object has acted on the silver emulsion of a plate exposed in the camera, it causes a fine precipitate of black reduced silver particles over each of the starch grains. In the transparency, these particles break up and scatter the light, so that it no longer reaches the eye as periodic waves, but in the form of scattered waves of red, green, and blue, which, mixing together, leave on the eye the impression of white. This, in the opinion of the writer, is why a white object can be photographed as white (see § 6 in Chapter I.,

entitled "On the Nature of White Light"). For a complete account of the microscopic appearance see Prof. Forster's very interesting paper, entitled "Wie ensteht das Weiss auf Dr. Lumière's Autochromplatten." Zeitschrift fur wissenschaftliche Photographie, Band IX., Heft 9, 1911, Leipsig.

CHAPTER VIII

PRACTICAL DETAILS OF THE WORKING OF SINGLE COLOUR-SCREEN PLATES

§ 44. **Choice of a Plate.**—Whatever make of colour plate is selected, it is advisable to use as fresh a packet as possible.

Messrs. Lumière now pack the plates face to face between black cards, and guarantee the plates good for at least six months after the date stamped on the box. My experience in South Africa does not coincide with this. I find that plates begin to deteriorate even before the date stamped on the box has expired. This remark applies to all single colour plates. I have shown in another place (§ 73) how stale plates may be revived. Autochrome and Dufay plates are now packed in boxes bearing the date up to which they may be used, and it would be well if other makers were to adopt the same course. Plates used after the date stamped on the box are found to be less sensitive, requiring two or three times the usual exposure, and moreover, the colours are somewhat dull. Still older plates show other marked signs of deterioration, and are apt to become veiled with fog at times.

Each make of colour-plates has certain advantages and certain disadvantages, and the reader must judge

for himself which to get. We may say, however, that the Autochrome plate gives the greatest and the truest range of colours. The Dufay and the Jougla plates are the most brilliant in the colours, while the Paget separate plates are by far the most rapid. The latter make of plates, however, present considerable difficulties in manipulation, and the reader must not be surprised if he should fail in getting a good result. The writer had many failures before he finally succeeded in producing a fairly satisfactory picture. Lined ruled plates are open to the great objection that they form a screen and thus give rise to diffraction spectra. These spectra are very noticeable when held up in front of an artificial light, and the brighter the light and the narrower the rulings the more conspicuous are the spectra. In the Dufay Dioptichrome plate the lines are broken up by squares, and so there is hardly a trace of spectrum bands, for they cannot be perceived in daylight, but in the Warner-Powrie positives the spectra are so marked in daylight that the pictures are practically worthless. In the Jougla positives the spectra are very conspicuous by artificial light, but are only slightly noticeable by daylight. Of course the Lumière plates exhibit no trace of spectra since there is only a mosaic of dots. For the same reason the Krayn plates are free from spectra, but the squares are very large, and hence the definition is coarse.

There can be no question that for all-round work the Lumière plates give the most satisfaction and are the easiest to manipulate, but the Dufay plates are capable of producing the finest results of any plate in the market. Some of the positives are exquisite in their

brilliancy, richness of colour, and sharpness of outline, while all colours except blue are perfectly rendered; but the blues have much too green a tinge, especially the skies. On the other hand, red, orange, yellow and greens of all shades are superb in their brilliancy and delicacy of tones.

§ 45. **Processes concerned in making a Single Colour-Plate Picture.**—The following 27 headings should be carefully studied by the Amateur who wishes to obtain a perfect finished picture:—

1. The camera.
2. The lens.
3. Choosing the subject.
4. The insertion of the plate in the slide.
5. The colour filter.
6. Focussing.
7. Use of a hood.
8. The exposure.
9. The dark-room lamp.
10. Processes concerned in the formation of the colour positive.
11. First development.
12. Reversing the image.
13. Second development.
14. Clearing and hardening.
15. Intensification.
16. Reduction.
17. Drying the positive.
18. Varnishing.
19. Covering the positive.
20. Final improvements of the tones of the image.
21. Binding up the colour screen.
22. Defects in colour positives, causes and remedies.

23. Copying of colour plates.
24. Indoor colour-plate portraiture.
25. Lantern projections in natural colours.
26. Resensitising colour screen plates.
27. Repairing light-filters for colour photography.

§ 45—1. **The Camera.**—Any camera which takes plates, and not films only, may be used, since a colour plate is exposed exactly in the same way as any ordinary plate, the only difference being that in colour photography a yellow filter is essential, whereas in ordinary photography it is optional. In the same way any dark slide may be used, but it is as well to use one that has plenty of room inside, for it must be borne in mind that the plate is reversed (glass side towards the lens), and as the film is exceptionally thin, and liable to be scratched or torn, nothing should be allowed to touch it except velvet or smooth tissue paper. If the makers would only construct dark slides, so that the film side of the plate merely rested along the edges of a rebate, enabling the surface of the plate merely to face, without actually touching, the partition between the two plates, it would prevent those flaws and green spots from appearing after development, which so greatly mar the picture. If you cannot get a slide made like this, it will do equally well to protect the film by a frame of cardboard $\frac{1}{8}$th of an inch wide, on which the edges of the plate rest, and then remove the spring of the partition flap. This is Grant's device, and answers admirably if the slide is a folding one. If you have a solid dark slide, such as Ross and many others provide, it is a good plan either to cover each side of the card partition with black velvet, or to gum the edges of two or three

sheets of fine tissue paper round the margins of the partition. In the case of Paget separate plates, the screen and sensitive plate must be kept tightly in contact by means of a strong spring, or else the colours will not be properly formed in the positive.

§ 46—2. **The Lens.**—One may take a picture in colour with any lens, but in order to get the finest definition, a lens should be chosen which will bring not only the yellow, green and blue, but the orange and red rays to a common focus. In photography, with ordinary plates it is not necessary to bring the orange and red rays to a focus, since the film is not affected by them, but in all colour work, and in ordinary photography when isochromatic or panchromatic plates are used, three rays must be brought to a focus, viz. the red and the blue and the yellow. There are a large number of lenses which will do this in a satisfactory manner, in fact, almost any anastigmat lens will accomplish it, especially if made by a first-class firm. At the present day three principal types of lenses are in common use. The Petzval portrait lens, the Aplanat, which is a cheap but very efficient lens for ordinary photography, and the Anastigmat, which is the lens par excellence *for all purposes.* It is a much more expensive lens than the other two, but owing to its superb definition, wide aperture, great covering power, and to the fact that all the rays of the visible spectrum are practically brought to a common focus, it forms an ideal lens for colour photography. Such lenses are made by all the best firms—Zeiss, Goerz, Dallmeyer, Ross, Watson, Cooke (Taylor & Hobson), Beck, Stayley, Aldis, Voigtländer, Busch, Lacour-Berthiot (Paris), Salmoiraghi (Milan),

and many others. The reader will not make a mistake if he procures an Anastigmat from any of the above-mentioned firms.

Which is the best focal length of lens to use? For ordinary photography a lens having a focal length equal to the diagonal of the plate is generally recommended. Thus for a quarter-plate a $5\frac{1}{2}$ in. or 6 in. lens, for a 5×4 plate, a $6\frac{1}{2}$ in. or 7 in. lens, and for a half-plate an 8-in. lens will be found to give the best all-round results. In colour photography, however, a lens having a much longer focal length will be found to give more artistic results. In fact, the lens suitable for the next larger size of plate should be used. Professor Miethe goes even further, and recommends a lens of 14 to 17 cm. ($5\frac{1}{2}$ in. to 7 in.) for a lantern slide, one of 7 in. to 8 in. for a quarter-plate, one of 8 in. or 9 in. for a 5×4, and one of 10 in. or 12 in. focal length for a half-plate. The reasons for this are several. First, there is always a danger of overcrowding too much on the plate. With a black and white picture this does not matter so much, as it can always be enlarged, and this is always done if the photographer intends to put a lot of work on the print afterwards. With a colour positive, however, an enlargement is not only a more difficult and tedious business, but the picture loses a great deal more by enlargement than an ordinary negative, for reasons which we have given elsewhere. Secondly, what one wants in a colour picture are large surfaces of one colour, rather than a number of tiny patches of different colours. With a short focus lens this is generally the case, since the magnification is so small, and one is

apt to get a profusion of small coloured objects which carry the eye all over the picture, instead of the eye being arrested by the principal subject, as it ought to be, and thus the general effect is spoilt. Again, with a short focus lens the background will appear too small in comparison with the foreground, an effect which will always destroy the balance and harmony of the whole. Of course these remarks apply equally well to every kind of colour photography.

§ 47—3. **Choosing the Subject.**—In choosing a subject, avoid too much contrast in the lighting. In ordinary photography deep shadows and brilliant high-lights often contribute largely towards forming a harmonious picture, but in colour photography extremes of light and shade when in large masses and in the same picture are very difficult to develop properly, the reason being that the high-lights have to be greatly over-exposed to bring out detail in the dark parts and shadows. Now, as we shall see, a greatly over-exposed subject will be eaten away in the reversing bath, and leave a thin detail-less picture, while the under-exposed dark subject will be dull, heavy, and opaque. For example, if a portrait group be taken against a very dark laurel or holly bush, the flesh tints, and white costumes especially, will appear washed-out and thin after reversal, if development be carried far enough to bring out the details of the dark leaves. On the other hand, if the figures be rightly developed the leaves will come out dense and without detail in the reversing bath. Of course, in many cases, this latter adds to the pictorial effect. If, however, detail everywhere is wanted, the only thing to be done is to take

the portrait over again, either with a much lighter background, or if that is impossible, by using a concentrated developer to secure detail in the shadows, and long before the development is finished to pour it off, rinse the plate, and renew development with a dilute developer, so as to allow the image to become strengthened very slowly. In the same way, it is almost impossible to photograph the interior of a church and at the same time get good colours in the windows. This can only be done either by using the modified developer just mentioned, or else by brushing over the windows, as soon as development has begun, with a solution of Bromide of Potassium, so as to restrain the action of the developer locally. Above all, it is essential to give the correct exposure for the dark parts and shadows.

The correct exposure is the key to the whole position, and the greater the contrasts the more necessary it becomes to get it absolutely right. Then the modifications in development above described will secure the desired result.

Groups and portraits often come out better if taken when fully illuminated by sunshine. This, as the reader is well aware, is not the case with ordinary photography, but in colour work, the colours come out much more brilliantly in full sunlight, and the result is not a flat picture, as one would expect, but often a most pleasing effect is thereby attained without any appearance of flatness.

§ 48—4. **Insertion of the Plate into the Slide.**—The plate should be inserted into the slide several feet

away from a *very feeble* yellow-green or "Virida" light (see § 53), taking care to have the glass surface facing the lens, in order that the light may pass through the starch grain filter before reaching the film. The bright reflection of the lamp will show at once which is the glass side, as the coated side does not reflect the light at all. Most plates are packed film to film, with two pieces of thin brownish paper between them. These need not be removed, but a black card [1] should be placed on the top of the paper, and then the plate covered with both, should be placed in the slide. In this way the film is doubly protected both from dust and friction, as well as from any stray light. A better plan still is to have the slides reconstructed so that the whole of the film except the extreme edges rests against air only, since the card, pressed by the spring, may act on the plate injuriously. This prevents contact of the film, except along the edges, so that there is no chance of abrasions whereby the water may soak in and give rise to green or other pigment stains during development.

§ 49—5. **The Colour-Filters.**—In order to give the correct values to the three colours during exposure, it is imperative to put a colour-filter either in front of or behind the objective, so as to reduce the excessive

[1] A white card will do just as well, and if placed in contact with the film will reduce the exposure to about $\frac{3}{5}$ths, *i.e.* if using no card at all, or a black card, the exposure required is 10 seconds, with a white glazed card the exposure will be 6 seconds. Be careful not to expose the glazed card to bright sunlight as the glaze is often fluorescent and the luminous exhalations are apt to fog the plate slightly. Interference phenomena have no effect on the image.

action of the blue end of the spectrum. If no filter at all is used, or unfiltered white light gets access to the plate, the final image will appear throughout of a violet-blue colour. Moreover, any ordinary yellow screen will not give correct values; in fact, the attainment of the correct colour is one of the difficulties which all makers of screen-plates have had to overcome, since not only must the ultra-violet rays be absorbed, but the correct proportion of the spectrum colours must be arrived at, so as to get the right balance of colours. The filter which Lumière finally adopted (auto-filter) consists of a piece of glass coated with gelatine, and stained a delicate rose orange-yellow colour, and protected by a second piece of optically worked glass. The Lumière filters are issued in five sizes, in a square form. This is an awkward shape, as it takes up too much room and requires a box adaptor to attach it to the lens. Both Ross and Sanger Shepherd & Co. undertake to trim and grind these square screens to circles, which is the most convenient form, as they can be fitted either into split rings or solid rings, which screw on to the flange of the lens, or let into the lens cap with the front removed. These latter methods allow of the filter being left on the lens, and one runs no risk of leaving it behind, or forgetting to put it on before exposure. It is quite easy to shape the square to a circle one's self. It is only necessary to mark the circle in ink on one of the surfaces, and then crunch off small particles of glass through both thicknesses at once with an optician's edging shanks, until the circle is reached. A couple of minutes' work on a grindstone will round it off to a smooth edge. The glass will break if a

diamond be used, because the two faces are cemented together.

Wratten's K1 Filter does fairly well for Thames plates, but is useless for Autochromes. It is, however, necessary to supplement the ordinary filter when exposing upon snow or ice by a second filter, owing to the great excess of blue-violet light in these cases.

When copying oil-paintings, especially in a gallery, a lighter tint filter gives better results than Lumière's auto-filter, which we have referred to above. Lumière supplies one under the name of "Auto-JM filter."

§ 50—6. **Focussing.**—As the film surface of the plate is turned away from the lens, it is advisable to reverse the focussing ground glass (or both ground glasses in a reflex camera). Then the plane of the film will correspond with that of the image surface of the ground glass, and whether you put the colour-filter in front or behind the lens it will make no difference, because the correction due to the filter is made with the eye when focussing. If no ground glass is used, and the focus adjusted by the scale, when the filter is placed behind the lens this will just correct the error, because the filter is usually 3 mm. thick, and the colour plate 1·5 mm. Now, the effect of a filter behind a lens is to lengthen out the focus one-third of the thickness of the filter. But in this case the light passes through two plates of glass (viz. the colour filter 3 mm. thick and the sensitive plate 1·5 mm. thick), the displacement will therefore be one-third of (3 mm. + 1·5 mm.), or 1·5 mm. behind the front (or glass) surface of the plate. Therefore, this displacement of the focus just coincides with the thickness of the sensitive plate (since it is reversed and the

film is now behind), and no adjustment will be needed, unless a thinner plate be used, say of 1 mm. thick, when it will still be necessary to rack out about 0·3 mm. If the filter is in front of the lens it will have no effect on the focus if the object is at some distance, *i.e.* if the lens is in focus near the infinity mark. In this case the lens must be racked *in* an amount equal to the thickness of the sensitive plate (1·5 mm.). If very small-sized plates are used, a movement of 1 mm. *in* will suffice.

§ 51—7. **Use of a Hood and Effect of Shadows from Coloured Objects.**—It will often be found advantageous to use some form of hood in front of the lens, so as to screen off all the light not actually used in forming the picture. For this purpose one with an oblong opening, the size and shape of the picture, gives the best results, as all rays are cut off which do not enter into forming the picture, and which would interfere with the purity of the image. In ordinary work this is of little consequence, but in colour work all reflected light spoils the purity of the colours, either by shedding white light (which is a mixture of all the colours), or one particular colour, on to them. Thus, a green object casting a shadow on a red object will give rise to an orange-yellow, or a bright silver teapot on a red tablecloth will appear splashed with red or pink owing to the red light reflected from the cloth on to the teapot. Hence in portraiture it is not uncommon to see the neck of the sitter appear of a greenish-yellow colour owing to the reflected light from an adjacent mass of green leaves being thrown across it, but it is only right to add that under-exposure is often responsible for this. Another point is to regulate the

exposure so as to give the correct exposure to both sky and foreground in the picture. This can be done by means of a flap-shutter, a guillotine (up and down) shutter, or a black card moved up down by the hand. You may get a blue sky and clouds with correctly exposed landscape in several ways. First, you may give a shorter exposure to the sky, by means of a flap-shutter or a screen. Secondly, you may over-expose the whole subject about twice and considerably shorten the time of development. Or, lastly, you may lift the plate out of the developer and then pour a little water containing 1 % Bromide of Potassium over the sky area of the plate, returning it immediately to the developer, repeating the process three or four times if necessary. In fact, generally speaking, the plate may be treated, under special circumstances, in much the same manner as in dealing with a similar subject on an ordinary plate.

§ 52—8. **The Exposure.**—The right exposure is a matter of great difficulty. This is the more to be deplored as the success of the finished picture depends largely on the correct exposure. This is so, to a far greater extent than is the case with ordinary plates. As a rough guide, it may be said that one should under-expose for subjects taken in sunlight and at midday in summer, and considerably over-expose (two or two and a half times the calculated time) in dull light, or towards evening, or for objects in the shade. You may use either Wynne's or Watkins' or the Imperial plate Actinometer, which is calculated on Hurter and Driffield's

numbers,[1] or else Wellcome's exposure record. The latter gives you the Autochrome plate speed with colour-filter *Indoors as* 24, *Outdoors* 12, which speed we may compare with Imperial Special Rapid or Flashlight. The Autochrome filter increases the exposure about five times; the starch grain backing about six times, while the film is about the same speed as an Imperial Rapid. If, therefore, you take an Ilford "Zenith," an Imperial "Sovereign" plate, or a "Premo Filmpack," and use any one of them without a filter in a good light and give minutes for seconds, you will get about the right exposure under similar conditions for a Lumière Autochrome plate with filter. Whatever you do, beware of under-exposure. An under-exposed plate can never yield a perfect picture; an over-exposed plate, even up to three times the correct exposure, can be turned into a splendid positive if carefully restrained during development by bromide of potassium, and by diluting the developer with water. In photographing sunsets rather underdevelop than overdevelop; overdevelopment ruins sunset effects.

§ 53—9. **The Dark-room Lamp or Safelight.**—Since the film of an Autochrome, Omnicolore, or any other three-colour plate, must of necessity be a Panchromatic one, it is obvious that the same light should be used for all red-sensitive plates. Formerly the writer

[1] H. and D. is equivalent to 1½ Watkins, so that to convert H. and D. into Watkins, add one-half; or take one-third off Watkins to obtain H. and D. equivalent. See Appendix, Table 1 for correct exposures. For Autochromes out of doors use H. and D. 2, Watkins' Meter 3, Wynne's Meter 11. For Paget plates use H. and D. 5, Watkins' 3, and Wynne's 18.

used a very suppressed dark red safelight, consisting of two sheets of ruby glass, one sheet of orange-red wrapping paper, and two of canary yellow fabric, but a bluish-yellow-green light is unquestionably safer and less irritating to the eye than a deep ruby red. Besides, as Purkinje first pointed out, blue and blue-green colours are more readily perceived in a dim light than red or yellow (see § 25). An admirably safe coloured paper is now sold, in packets containing yellow and green sheets, by Messrs. Lumière, under the name of "Virida" Paper. For use take three yellow, and two bluish-green papers. Cut them to the size of the lantern window and place all six together between two sheets of plain glass, and slide them into the groove of the lamp in the place of the usual red filter. The three yellow papers are recommended to be placed next the light. The writer uses an extra bluish-green paper gummed on to a plate of glass, which he places in front of the lantern until development is half completed. A developing lamp is now issued by Messrs. Wratten and Wainwright which has some excellent features. It is so constructed that only diffused light is seen, the direct rays from the gaslight or lamp being entirely blocked out, but those rays which spread backwards are reflected by a bent sheet of white enamelled metal through the yellow-green screen. Thus the light is not only safer, but is much softer and more uniformly distributed. Wratten's screen consists of a sheet of glass coated with a bright yellow gelatine film, one coated with a bright green film, and a thick sheet of specially tested green paper between the two.

Some operators soak the plate in the developer for

two minutes in total darkness, before adding the alkali accelerator, which starts the development. This desensitises the plate sufficiently to allow of an ordinary deep red light being used. Others soak it in a 2% solution of soda bisulphite or metabisulphite to which a little Bromide of Potassium has been added. This effects the same purpose.

§ 54—10. **Processes concerned in the Formation of the Coloured Positive.**—The treatment of the exposed plate, in order to obtain the complete picture, appears complicated, and is apt to frighten the beginner, but it is really an exceedingly simple process, and only occupies about fifteen minutes from the time the plate is put into the first developer to the completion of the positive. If you omit intensification, clearing, and varnishing (none of which are essential), everything necessary can be done with two solutions, viz. a developer and a reversing solution, as the same bath serves for both first and second development.

§ 55—11. **First Development.**—This, as well as all subsequent operations, excepting the reversal process, are exactly the same as with other plates. Pyro-ammonia, Pyro-soda, Metoquinone, Quinomet, and Rodinal all give excellent results.

The chief thing to remember is that when working with Autochromes you must cut down the time of the various washings as much as possible, as, owing to the extreme thinness and delicacy of the film, it will not stand long immersion in any liquid, nor will the film stand a jet of water, such as would have no effect whatever on an ordinary negative film. With other colour plates it does not so much matter. The

following method, recommended by Lumière, is reliable, and if the tyro follows it carefully he will certainly correct his under- or over-exposures very materially.

§ 56. **Rules for Development.**—Clean two white porcelain or glass dishes. See that the water and developer are of the right temperature, between 55° F. and 65° F. This is of the utmost importance. If it is too cold you will not get the image out properly, if it is too warm you will get frilling and over-development.

For a quarter-plate or 9 × 12 cm. plate put 40 c.c. (1 oz. 2 drms.) of distilled water (by preference) into a cup. Add to it 2·5 c.c. (42 m.) of concentrated Quinomet developer. Place it by the lamp.

Into a second smaller measure put 7·5 c.c. (2 drms. 8 m.) of same developer. Place it next to the other measure.

Adjust your watch or clock so that the minute hand is at a full minute when the second hand reaches zero. Put the watch in the best light possible. Place the Lumière development time-table near the lamp, or, better still, write it in Indian ink on the outermost paper of the lamp (see Appendix, Table 9, p. 272).

In a separate dish place the Acid Permanganate or Acid Bichromate solution. Put it anywhere away from the lamp. Place the dark slide in a dry place away from the light. Light the green lamp, let your eye get accustomed to the green light, and then note the position of everything you want before making the room dark.

When all is ready remove the plate from the slide carefully. Put the plate film side (lighter side) upwards in the dish, *in almost total darkness*, and *holding*

it in shadow near the lamp; wait until the second hand is about to reach zero, noting at the same time the position of the minute hand. Then pour the developer over one end of the plate, cover the dish with a card, and rock well, so as to cover up instantly any islands of film that may form. After 12 seconds hold the dish nearly at right angles to the light, so as not to allow much light to fall on the surface, uncover the dish and watch for the first indications of an image other than sky. The moment the image begins to be visible you can let more light fall on the plate. Then note the position of the second hand, and immediately pour the 7·5 c.c. Quinomet solution over the plate while rocking. Put a cover over the dish and gently rock the dish until the time is up according to the time-table. If the image fails to appear after 40 seconds, add 22 c.c. of Quinomet. If no image appears at the end of 60 seconds, it will be hopelessly under-exposed. The only chance is to add an ounce of water and leave it for another minute. If the image begins to appear, prepare some fresh developer (33 c.c. of Quinomet to 1½ oz. of water), cover up the dish and wait until the image is dark enough, examining it for an instant from time to time, until, on holding the plate horizontally against the light, the details of the subject can be clearly perceived. These details need not be nearly as dark as they should be in an ordinary negative. Then wash well in a dish, pouring the water off and filling up again about five times.

If you prefer a Sodo-Pyro or Hydroquinone and Metol developer you can pour over the full strength

solution right away, watch for the appearance of the first trace of image, neglecting the sky, multiply the time by the factor number, and cover up the dish with a card until the calculated time is up, then rinse well in the dark and place in several baths. In developing the plate there are three marked stages. First, a gradual strengthening of the image until it reaches a certain maximum; second, the image gradually loses strength until it has almost disappeared, owing to the loss of opacity of the white emulsion. The darker parts of the image remain, but they appear transparent; third, if the development be pushed beyond this stage, the image in the clear parts gradually change into a positive. It is at the second or transparent stage when development must be stopped to get the finest result.

§ 57—12. **Reversal of Image.**—The negative (still in the dark) is now put in a clean dish and the acid permanganate solution (or acid bichromate solution) poured over. Rock well for a few seconds. Cover up the dish for half a minute and then turn up the gaslight. After three or four minutes remove the negative (now a positive) and wash in four or five quick changes of water as before. The image should be examined from time to time in daylight or gaslight, and reversal stopped the moment all the details are fully out, otherwise the high lights will be eaten away and detail lost in them.

§ 58—13. **Second Development.**—Expose the positive to bright daylight for a few seconds, or, if at night, burn a foot or two of magnesium six inches from the film, holding the plate upright to avoid any ash falling on

the plate, or hold it close to an incandescent burner or Osram lamp for a minute or two. (If you have no ribbon, or are called away, shake off the superfluous water and leave it to dry anywhere in subdued light. It may then be developed at your leisure.) Then put the plate in the first developing bath in bright daylight and leave it there until the positive becomes uniformly dark, in fact nearly or quite black, by reflected light, which occurs after three or four minutes. This process must be very thorough if intensification is required afterwards, because the necessary hypo bath afterwards will cause the image to fade if the second development is incomplete. Rinse well under the tap.

§ 59—14. **Clearing.**—If the image looks dull and somewhat brownish it may be cleared and rendered bright by soaking in a weak 1 % solution of Sodium Bisulphite, or the old reversal solution diluted to a pale colour, about one part to 20 or 30 of water. The plate should not be left in the bath more than 30 seconds.

§ 60—14A. **Hardening.**—This is optional, but useful, as it brightens up the picture and hardens the film. Put the plate in a bath, made by dissolving about half an ounce of chrome alum to a quart of tap water. It may be used over again a great many times, or you may use 1 part of alum, 2 parts citric acid, and 100 parts of tap-water. This is a favourite bath of the writer's; it may be used over and over again. Formalin solution, 1 %, is also recommended. It is essential to use one of them in hot weather, or if the temperature of the water or developer exceeds 65° F.

Wash the positive in four or five quick changes of

water (3 or 4 secs. between each change). Shake off superfluous water and let it dry in an upright position. The positive is now finished, provided it has been correctly exposed and developed.

§ 61—15. **Intensification.**—Often the colours are not bright enough, or they are too thin and watery, or lastly, they are dull, heavy and dense. For the two former cases intensification will probably put matters right. In the latter case reduction will increase the transparency and brightness, giving the transparency more "pluck." It must then be intensified to bring up the colours. We will first give the explanation and then the practice of Intensification.

§ 62. **Explanation of the Process of Intensification.**—If the positive looks weak and the colours are not as bright as they should be, it should be intensified. The following diagram shows what happens. We have seen that in the positive the complementary colours are hidden behind a deposit of blackened silver. When the positive looks weak the deposit is too thin, and the contrast between the transparent parts and the veiled parts is not sufficiently prominent. If, therefore, we intensify the deposit by adding another coat of blackened deposit to it, the contrast between the two will evidently become more vivid. This, in a word, is the *rationale* of intensification.

Suppose a bright orange object which consists of a full measure of red, some green and a trace of blue, be photographed, the positive, if correctly exposed in the first instance, will show in section an appearance similar to Fig. 18. Here all the bromide of silver behind the red grains, about half the green and a

quarter of the blue, will have been acted upon and dissolved. If the plate is under-exposed, the proportions will be altered. Only half the silver bromide behind the red, a quarter of the green, and a mere trace of the blue (Fig. 18) will be reduced.

If now we reduce this deposit by a dilute solution of acid permanganate we can take a layer of deposit off the whole of the film, so that we may have about three-

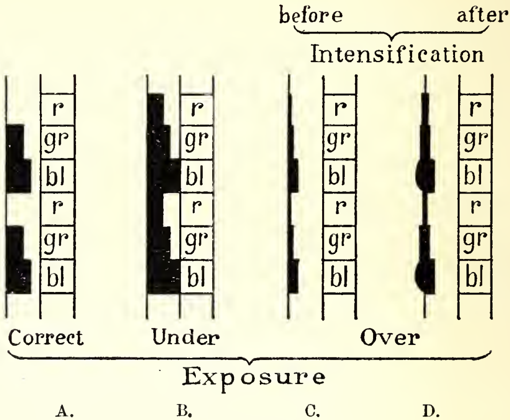


Fig. 18.

quarters clear glass behind the red, nearly half behind the green, and a quarter behind the blue. In this way we can improve the picture. If the plate be over-exposed, it is obvious that a much larger quantity of bromide of silver would be acted on by the light and reduced to silver by the developer, and as this would all be dissolved away by the acid permanganate, we

should get nearly clear glass behind the red and green, so that there would be very little left to redevelop, and a section would resemble C (Fig. 18). If this layer be intensified by any method, we should again get an appearance more like D by increasing the deposit over the green, but much more in proportion over the blue. In this way the contrasts will be heightened and the colours made more brilliant, since the blue which is the opposing colour is nearly blocked out, and so allows the red and green to shine unopposed by their complementary blue. As, however, the deposits behind the red would also be increased, whereas in the correctly exposed positive there was none at all, we should change a dull yellow into a brilliant yellow instead of a brilliant orange, as it ought to be. This also shows us how the slightest error in any one colour will always upset the proper proportions of the other colours, which will be still more disturbed on any attempt to freshen up the colours by intensification or reduction, although either may greatly increase the brilliancy and beauty of the image.

In the same way any alteration in the intensity of illumination of the object will modify the colours, since we have reasons for believing that Purkinje's Phenomenon holds good for the plate as well as for the eye. On the other hand, if the total amount of light reaching the plate is the same in two cases, no matter how it is portioned out, the result will be the same. Thus, if you photograph a well-lighted grey-coloured object with a lens working at F/4, exposing it for two seconds, and photograph again with the lens stopped down to F/8 and give four times the exposure,

the two plates, if developed together, should give identical results.

Intensification is best done immediately before, or after removal from the clearing bath. Either Lumière's Pyro and Silver, or the Mercury and Sulphate formula gives excellent results; the latter is somewhat more intense but less under control than the former. Both may be used one after the other if great intensification is desired. Lumière's formula (indicated by the letters F and G in his original instructions for developing Autochromes) is: F, Pyro 1 gm., Citric Acid 1 gm., distilled water 30 c.c.; G, Silver Nitrate 1·65 gm., distilled water 30 c.c. (Note, add G to the water before F, or you may get a precipitate.) For use take 5 c.c. of each and pour into 55 c.c. of distilled water. Pour over the plate immediately the solution is made (or the solution will turn black), rock and examine from time to time until sufficiently intense, or until the bath becomes turbid. (See Appendix, Table 11.)

The mercury and sulphite intensifier (see Appendix, Table 11) is a very safe and reliable one. It may be varied in several ways after the first bath. You may use either Sulphite of Sodium or Sulphite of Potassium 5 % solution in water, or you may re-develop with any developer you choose, except Pyro (which has too much colour). Ferrous oxalate[1] produces a beautiful blue-black deposit which, by quite obscuring the complementary colours, will give very vivid tones.

[1] Ferrous sulphate, saturated solution 1 part.
Oxalate of potassium do. do. 4 parts.
Leave to settle, and pour lear liquid for use.

In this latter case it is well to soak the plate immediately afterwards in a dilute solution of Citric Acid, to dissolve away any oxalate of lime which may be formed by the oxalate of Potassium uniting with the lime in the tap water.

Lastly, Piper and Carnegie's Chromium intensifier may be recommended.[1] The author does not advise a Uranium intensifier, as it upsets the balance of colours and results in a mess. After intensification it is occasionally advisable to use a clearing bath of neutral Permanganate 1% solution, which will at once remove the yellow stains which creep over the whites during prolonged intensification. If the colours are not impure the clearing solution may be omitted, but the fixing bath must be used if the plate has been intensified by the Pyro-silver method. This, according to Lumière, is essential if the plate has been intensified at all, otherwise it may be omitted.

§ 63—16. **Reduction.**—This is often needed when the shadows are too dark and obstruct the colours, or the high lights are obscured; also in portraiture when the hands and face are too brown. It may be effected in several ways. (See Appendix, Table 12.)

1st. By immersion in the *Acid* Permanganate or the *Acid* Bichromate bath, diluted 1 to 10 parts of water.[2] The image must be constantly examined and plate flooded with water the moment the reduction is sufficient.

[1] This is sold in tabloid form by Burroughs Wellcome & Co., Holborn Viaduct, and all Photographic Chemists.

[2] The undiluted bath must not be used for this purpose, or it will take the whole image away.

2nd. By using the Ammonia Persulphate reducer.

3rd. Farmer's solution.—This solution, so valuable with ordinary negatives, is apt seriously to reduce the brilliancy of the colours owing to the Hypo dissolving the bromide of silver unacted on by the 2nd developer (unless the redevelopment has been very thorough). If this precaution is attended to the result is most satisfactory.

The mischief can usually be remedied by reintensification. Whatever reducer is used, the action must be very carefully watched, and it is well to begin with a weak one.

The positive is then washed and allowed to dry.

§ 64—17. **Drying the Positive.**—This may be done by fixing it on a whirler or in front of an electric-driven fan, which dries it very rapidly. The plate may, however, be dried just as well but more slowly by shaking it a few times, drying the back and placing it vertically against a support. If after a few minutes any large drops have collected on the surface they must be shaken off, since, owing to the restricted washing imperative with these plates, the surface water still contains traces of impurities, which on evaporation will give rise to faint marks.

One must never attempt to hasten drying by holding the negative to the fire. If there are any drops of water on the film, these will become heated and melt the film beneath, leaving a nearly transparent spot or a blurring of the image. In any case the experiment is a risky one. Drying with blotting-paper is also dangerous. Soaking in alcohol to hasten evaporation may cause the colours

to run. Hence, natural evaporation is the only safe procedure. At a temperature of 65° an Autochrome plate should be dry in 30 to 40 minutes. Omnicolore and Thames plates will take considerably longer, owing to the thickness of the films.

§ 65—18. **Varnishing.**—As I have stated, varnishing is not necessary, but it brightens the image and makes the colours more vivid, and prevents the heat of the projection lantern from injuring the film. It requires an experienced hand to do it properly without leaving lines and ridges of varnish, which, unfortunately, are not entirely transparent. If they do occur, the best plan is to lay the plate in a bath of benzine, when the ridges will dissolve and disappear. As a rule the difficulty of varnishing arises from the varnish being too thick. In this case thin it down with some benzole, McIntosh recommends pouring the varnish over the positive while on a whirler. He commences the whirling before it has had time to set. The author believes that an alum and citric, or chrome alum bath will clear and harden the film quite effectively, and the heat of the lantern will not crack the film more than a varnished non-hardened one. Spotting out should be done by means of transparent colours, otherwise whatever colour you use will appear black when you view the positive as a transparency. You may mix the paint with a drop of gum or oxgall, to allow of its biting the glass. The finest sable-hair brush procurable should be used.

§ 66—19. **Covering the Positive.**—The film should finally be protected by a plate of glass, and the two plates bound together with plaster strapping. The ordinary

paper binding strips are not to be recommended. They take a lot of time to put on. They do not keep the dust or damp out, which creeps in at the corners, and they are in many other respects unsatisfactory. By far the best method is as follows:—Procure a long strip of black or yellow rubber self-sticking surgical plaster, which can be obtained at any chemist's shop. It is sold on flat reels, each holding about ten yards, and about $\frac{3}{8}$ in. (1 cm.) wide. In order to bind, pull out enough plaster to go round all four sides of the plate. Lay it flat on the table, sticky side uppermost. Take the positive covered with the protecting glass in both hands. Place one side carefully midway between the edges of the plaster. Then lift up the reel, keeping the plaster on the stretch, and rotate the positive with its cover-glass over each edge in turn, keeping the plaster taut all the time, until you arrive at the point where you began. Cut the tape close to the glass, and then press the two sides of the tape against the sides of the glass. In this way two plates become hermetically sealed, and neither dust nor damp can get in. The corners can be pressed down at once, and do not need to be trimmed in any way. The whole process takes about twenty seconds to perform, and the result is admirable.

Of course, the same method will do equally well in the case of lantern slides. Seabury and Johnson make a good plaster, which is known as Mead's plaster. A German firm make an excellent black rubber plaster known as Gummi-Pflaster, which is even better than Mead's.

A mask of black, brown, or olive-green paper with

an opening of any desired shape may often be found useful to hide any defects or superfluities in the picture. It is cut to fit the size of plate, and placed over the film before covering with the protecting glass. When finished, the picture may be rendered much more effective by a suitable frame of metal, gilt, or dark wood, or by one of the many devices now on the market for screening the picture from outside light, or examining it by reflection in a mirror.

§ 67—20. **Final Improvement of the Tones of the Image.**—The protecting cover-glass affords a means of correcting the general tone of the picture. Thus, if there is an excess of blue in the foliage, it may be corrected by using the palest tinted yellow glass. If the red tone is redundant, a very pale shade of green (or of cobalt-blue glass if orange), may be used for the cover. The former will strengthen the yellows, the latter the blue of the sky. Another good plan is to coat a separate sheet of glass with a thin layer of gelatine, which you can stain any colour you please. Thus, for a yellow tint use a pale-tinted bath of Porrier's Orange II. For a pink tint, use Carmine. For a blue, Victoria blue or Turkey blue. For a greenish-blue, Methylene blue. The aim is always to select the complementary colour to the one you wish to counteract or modify. Often charming and totally unexpected results can be achieved in this way. Thus, if the transparency is too blue, a little yellow in the coating will produce a greenish tint, and an orange red will help a sunset, and so on.

Dyeing the film of the transparency itself has been recommended by Von Hübl, König, and others, but it

is open to great objections. Thus, you may easily overstain the film, or the stain may penetrate into the starch grains with disastrous results, or the effect may not be pleasing, and cannot be altered.

§ 68—21. **Binding up the Colour-Screen and Transparency of Thames or Paget Separate Plates.**—This is easily learnt, but requires a little manœuvring. If you place two screens in contact, coloured side to coloured side, and hold them up to the light, you will notice the discs of the screens (if you are using Thames screens) will form a coloured moiré pattern which, as you rotate the one or the other grows rapidly larger and larger until the pattern loses all shape and vanishes. If you continue the rotation, the pattern will again become rapidly smaller. Now substitute the transparency for one of the screens, placing the film against the coloured side of the screen as before, and move it until the pattern just vanishes, Fix the two with a spring letter clip and hold them to the light. If the colours are not quite right you must shift the positive ever so little one way or the other until, when holding the pair squarely in front, the colours are correct. Now fix three out of the four sides with clips and proceed to bind the remaining side with black adhesive binder. Then place a fourth clip over the binding and carefully remove the opposite clip. In this way registration may be secured without any shifting.

The effect of the picture is greatly enhanced by having it mounted in a wooden frame of plain black moulding, about 2½ to 3½ ins. in diameter, and curved so as to throw the picture into a recess, as it were. It

makes more difference to the appearance of the picture, than even a heavy broad gilt frame does to an oil painting.

§ 69—22. **Defects in Colour-Plate Positives—their Causes and Remedies.**—(1) **Under-exposure.**—This may be partly guessed by the length of time which has elapsed before the image begins to appear. After development, the image appears incomplete, hard and without details, buried as it were. After reversal the positive appears dark, dull, and heavy, and there is absence of all detail in the shadows. The remedy is to reduce with weak Acid Permanganate, Farmer's Solution, or Ammonium Persulphate.

(2) **Over-exposure.**—The image flashes up instead of slowly becoming visible here and there and gathering strength gradually over the plate. When the image is examined by reflected light after it is put in the reversing bath, it appears loaded with details and very dark. After reversal, owing to so much of the silver being dissolved away, the image appears weak, then transparent, and much of the detail eaten away. *Remedy.*—The moment you find the image coming up too quickly in the first developer, or the picture appearing at once, flood the plate with water, and prepare a freshly diluted developer with 5 to 20 drops to the ounce of a 10 % solution of Bromide of Potassium, and renew development, watching the image carefully. Stop as soon as detail appears in the shadows.

(3) **Yellow Stains and Dichroic Fog.**—If the development be prolonged unduly, or too strong a developer used, the whites may become stained yellow. *Remedy.*—Bathe the plate freely in 1/1000 Neutral

(*i.e.* non-acid) Permanganate of Potash, followed by half a minute in a fresh Hypo bath containing Bisulphite of Soda.

(4) **Brown Stain.**—*Cause.*—(a) Immersing plate in a bath of neutral Permanganate of Potash before all the developer has been washed out. This is especially liable if Pyro has been used as the developer. It can never be entirely got rid of. (b) The picture has been intensified by the silver method before the developer has been washed out, or the positive has been left too long in the Pyro-silver bath. *Remedy*—Wash thoroughly and immerse in 10 % sulphite of soda. If that fails, place in the reversal bath diluted 1 to 10 with water and then into Alum and Citric Acid bath.

(5) **Black Spots.**—*Cause.*—Insufficient action of permanganate reversing solution, by which small collections of reduced blackened silver particles remain undissolved. *To avoid.*—Examine the transparency carefully before redeveloping, and if you see any black spots put the plate back in the permanganate bath for a moment. *Remedy.*—Sponge the surface of the film over, both in the first bath and permanganate bath, with a soft cotton-wool pad dipped in water. Pick the spots off lightly with a needle, or, better still, a fine-pointed penknife. Lumière advises them to be dissolved out by means of a fine camel-hair pencil dipped in strong acid permanganate solution or in a mixture made up of Potassium Iodide 3 gms., Iodine 1 gm., water 50 c.c. This is too delicate an operation for most people, as the liquid is likely to spread a little, leaving a washed-out spot much larger than the black speck. In any case the camel-hair

pencil should be made of as few hairs and as fine as possible. The former method is quite easy, safe, and effective, therefore why run any risks?

(6) **White Spots** may be due to minute thickened specks of unsensitised emulsion. *Remedy.*—Scrape off with the point of a penknife. If due to bubbles, fill in with colour after varnishing.

(7) **Green Spots.**—*Cause.*—Abrasions in the film and access of water, which dissolves out the green colouring matter and spreads in an irregular circle round the crack. Also washing the plate for too long a time, by which the water has soaked through to the green stain and caused it to run. *Remedy.*—Cut the green spot clean out and then paint over space with a drop of solution of gelatine and let it dry; or put a smear of gum on the area removed, and fit in a bit of an old film of the right colour; or, lastly, varnish the plate after the patches are cut or scraped out. Then fill in the desired tint with any transparent colour. (*N.B.*—Chinese white is opaque to light and appears black in the transparency.) To prevent green spots use alum bath or 1/1000 pure Formaldehyde (or 1/400 Shering's Formalin, which equals 40 % of pure Formaldehyde). Either of these baths may be used before or immediately after first development. Also shorten the washing processes as much as possible, see that the water is not warm, and *above all never put off intensification or reduction until after the positive is dry*, if you do you are sure to get green spots (see Appendix 16).

(8) **Red Spots** frequently occur in Omnicolore plates. *Remedy.*—Pick them off with a fine-pointed penknife or needle.

(9) **General Violet Tone**.—*Causes.*—(i) Access of traces of white light to the plate which have not passed through the lens filter, or through the lens itself, *e.g.* a pinhole in the bellows, or chink in the slide, or space between the slide and back of camera, or minute traces of white light reaching the plate before or after exposure, or in the dark room.

(ii) The yellow filter is too small, and allows light to creep in round the edges when placed in front of the lens.

(iii) The yellow filter may have been forgotten.

(10) **General Blue Tone**.—(i) Under-exposure; (ii) Under-development. This latter may be used locally to give a blue sky and aerial misty effect.

(11) **Veiled Fog**.—(i) May be due to any of the causes of general violet tone; or to (ii) too much light in the dark room, or plate exposed too much to the light. If the light reaches the film side first, it produces general grey fog in the first developer. If it reaches the film through the starch grains, a fog, the colour of the light which reached the plate, will appear. Thus, if light from a red lamp reached the film through the starch grains screen, only the red rays would pass through and the fog would be red. In the same way a green light would cause green fog. *Remedy.*—These all disappear in the Permanganate Bath, but it has a tendency to thin the plate down and to degrade the colours. A good plan is to bathe plate for 1–2 minutes in the following solution—

Bichromate of Potassium .	1–2 gms. (12–20 grs.)
Hydrochloric Acid	0·35 c.c. (6 minims)
Water	100 c.c. ($3\frac{1}{2}$ ozs.)

If the positive shows the colours too weak, intensify by one or other of the methods given in the Appendix.

(12) **If the Brightness of the Colours disappears the moment the Plate is put in the Fixing Bath.**—*Cause.*—The second development was either too short, or else the developer was too weak or too cold (below 55°), the result being that some of the Bromide of Silver which ought to have been reduced by the second developer has not been acted on, and becomes dissolved away by the Hypo, leaving a flat, weak image. It is well, therefore, if you intend to use a Hypo bath, to leave the plate in the second developer at least three or four minutes.

(13) **Frilling or Blisters.**—*Cause.*—(i) The use of water at too high a temperature (above 65° F.); (ii) Careless handling; (iii) Differences in temperature of baths. The water may be cool enough, but the dark room much too hot. *Remedy.*—Chrome alum, or Formalin solution after first development. Also ensure that the baths are all about the same temperature. Autochrome plates are much better coated than when they were first issued. They rarely frill or blister now, unless the water or room is above 68° F., and green spots are seldom met with.

(14) **There may be a General Reddish Tint.**—*Causes.*—(i) Over-exposure; (ii) Too prolonged washing (should never exceed five minutes); (iii) The red light getting access to the film through the starch grains or grating. *Remedy.*—Bind up with a pale greenish-blue cover-glass.

(15) **If the Film is Scratched or Broken.**—*Probable cause.*—Friction of springs or card against the

film. *Preventative.*—Do not put the plates into the slide until absolutely necessary. Glue a raised border round the card, or place a piece of brown or dark coloured tissue paper between the film and the card.

(16) **If the Background of a Portrait or Group is of a Dirty Brown or Grey Colour (or the Picture appears clogged up or opaque).**—*Cause.*—Under-exposure or over-development. Development has been forced with too strong a developer, or prolonged to bring this detail out, resulting in a dirty, heavy, impure drab. *Remedy.*—Take the portrait over again with more exposure and weaker developer.

(17) **If the Face of the Portrait appears Thin and Eaten away.** — *Cause.* — Over-development brought about by trying to bring out details in a dark background. *Remedy.*—Nothing can be done to improve the positive. Expose another plate with a lighter background or one better illuminated.

(18) **The Picture looks Thin and suffers from Want of Detail, especially in the High Lights.** —*Cause.*—(i) Over-exposure; (ii) Over-development in first bath. *Remedy.*—Take the picture over again, with less exposure.

(19) **The Picture looks Dull and Opaque.**—*Cause.* —(i) *Under-exposure*; (ii) Under-development in first bath. *Remedy.*—First reduce with Acid Permanganate, or the Persulphate, or Farmer's reducing bath (see formulæ in the Appendix), then intensify with Lumière's Silver and Pyro bath (F. and G.), and repeat two or three times until the image is sufficiently dense. Bleaching, followed by Bisulphite of Soda or Quinomet, is very effective, but it is somewhat risky, as it is liable to

alter the tone of the colours and the contrasts. For the same reason Farmer's reducer might upset the balance of colours by forming a Silver Ferricyanide, which is somewhat irregular in its action. Lumière wisely recommends dilute Acid Permanganate for Autochrome plates, but Farmer's solution is better for thick films (*e.g.* Omnicolore, Thames, and Dufay).

(20) **The Colour has nearly all disappeared in Places, and the Positive resembles an Ordinary Positive.**—*Cause.*—(i) The film has contracted through the heat of an illuminating lamp, and slightly shifted the register of the picture on the starch grains. The plate has been dipped in an acid bath which has decolorised the starch grains. Too strong Citric Acid or too long immersion in it will take out the colour. *Remedy.*—(ii) None. Take the photograph over again.

(21) **The Positive after Varnishing shows a Number of Red-orange Spots.**—*Cause.*—Action of varnish on traces of developer left on the positive when the film, though apparently dry, still contains moisture. *Remedy.*—Dissolve off the varnish with benzole and immerse plate in 1 : 1000 neutral Permanganate of Potash. *To avoid.*—Soak the plate in the above solution before applying the varnish.

§ 70—23. **Copying Colour Plates,** *i.e.* of colour plates in which the sensitive emulsion film is attached to the colour-screens.

The reproduction of these plates is carried out in almost exactly the same way as lantern slides from a negative. There are two ways of doing it. 1st. The colour transparency may be placed in front of a camera and copied through a lens. This allows of

the size of the copy being varied. If you have a dark room and a window facing the daylight which can be blocked out by a shutter, so much the better. The author has a large square hole cut out of the shutter, into which he can fit plate carriers of various sizes. The transparency is fitted into a carrier suitable to the plate, and the latter is kept in position by two buttons. On the daylight side of the transparency he has a large board inclined at 45° and covered with a sheet of white paper. This reflects the light of the sky through the transparency. On a table facing the shutter is a long extension camera with an anastigmat of large aperture. To copy the same size, the lens is placed midway between the transparency and the plate, the two being separated by four times the focal length of the lens. A colour-filter is placed immediately in front or behind the lens, or between the combination if made of gelatine. The transparency to be copied should have the film side facing the ground glass, otherwise the picture will be reversed; and of course the copy must be placed with the glass side facing the light. The after-treatment of the plate is, in all respects, similar to that of the original. The other way is—

By Contact—This requires a very much shorter exposure than the previous method, but it is open to the objection that the film of the copy cannot be brought in contact with that of the original, but requires to be turned round so that the light traverses the colour-screen of the copy before it reaches the film. This may be obviated by using a small but bright source of illumination. Lumière recommends

a box (ABCD) (Fig. 19). The transparency (O) and copy-plate (P) are placed in the frame (HI). The film of the transparency is placed in contact with the glass side of the copy-plate. The source of illumination is a piece of magnesium ribbon (M) 2·5 mm. in width and 10 cm. to 20 cm. in length, according to the density of the transparency. This is folded double and pushed inside an iron wire spiral (S) (made by winding the wire round a penholder and then stretching it until each spiral is separated by a centimetre from the next) (Fig. 19). The end of the spiral is fixed by a screw

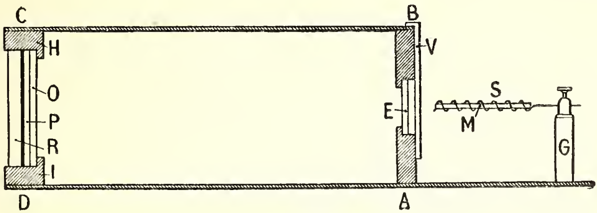


FIG. 19.—Autochrome Copying Camera.

into the support (G). According to Lumière the object of the magnesium in the principal axis of the camera is to prevent parallax owing to the separation of the film of the copy from the transparency by the thickness of the glass support. It is necessary that no other light should enter the camera, except that of the magnesium. E is a colour-filter, and V a movable slide.

In the case of a Paget plate in which the screen and film are on separate glasses, the copy is made by contact with the original negative taken through the screen. This gives a positive which may be bound up

with a new screen to give the colour, or used as a monochrome transparency.

In any case, copying a colour-plate from a colour-plate is not altogether satisfactory, because a third of all the light only goes through each coloured line or grain in the transparency to be copied, and of this only a third of the light, or $\frac{1}{9}$ of the initial light, gets through the second screen, since each coloured bundle of rays is stopped by two out of the three colours of the screen. Moreover, in the case of an Autochrome, whenever a coloured ray meets a clump of the complementary colour, the light is all absorbed, and the result is a black dot in the copy at this spot after reversal.

M. Gimpel first pointed out that whenever an Autochrome made in daylight is copied under the same conditions with the same light filter, the reproduction always possesses a predominant tint, which is usually yellow. This he overcomes by the use of a pale violet filter. But the difficulty may be overcome in another way. Instead of reversing and making a positive copy, the original negative may be fixed in hypo without reversal. In this case the inevitable predominant tint is reproduced in the copy in the complementary colour, and if made under the same conditions, the two will correct each other.

§ 70A.—**Achille Carrara's Method.**—The Autochrome is placed in a Lumière copying camera (see Fig. 19), in contact with a panchromatic plate. Instead of the Lumière filter he uses a set of analysis filters. In front of the filters he puts a sheet of fine ground glass (a fixed-out matt emulsion plate does well). The luminant preferred is a single filament of a Nernst

lamp, 5 inches in front of the filter. He first makes an exposure through the red filter. An average density Autochrome requires 30 secs. exposure with the red filter, and 90 secs. with the green or the blue filter. The negatives are all developed together with Rodinal solution 1·22 for five minutes, preferably with the addition of a few drops of 10 per cent. bromide. Prints can be made by any three-colour process such as Raydex, Autotype, or Sanger-Shepherd's methods. Sensitising is best done by his quick-drying Bichromate of Ammonia solution 1·5 of water, of which he takes 5 c.c. and adds to it 35 c.c. of alcohol for a 2 per cent. bath, 20 c.c. for a 4 per cent. bath, and 15 c.c. for a 5 per cent. bath. This he brushes rapidly over the tissue, which he pins on to a board, three times in succession, and then it is hung up to dry. In twenty minutes the tissue is ready for use.

§ 71—24. **Indoor Colour-Plate Portraiture.**—Owing to the prolonged exposure necessary it is extremely difficult to produce effective indoor portraits in colours. The difficulty may, however, be got over by using a flashlight powder in conjunction with a filter specially adapted to the light and the plate. The Lumière Co. provide their "Ideal" Autochrome Flash-powder, and a special "Auto P.O." filter.

The necessary installation is extremely simple, and may be completed in a few minutes in a studio or ordinary room. It consists of—

(1) The "Ideal" Flash-lamp (L) (Fig. 20), which by means of a pneumatic release fires a cap, which ignites the charge of Flash-powder.

(2) A strip of white semi-transparent fabric (B) such

as muslin, placed about 18 inches from the lamp, to diffuse the light.

(3) A white screen (R), to reflect the light on those parts of the sitter not directly lighted. (A white fabric stretched on a frame is suitable.)

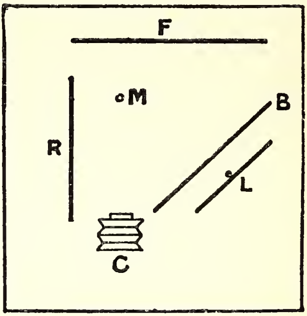


Fig. 20.—Diagram showing position of Camera, Sitter, Flash-light, and Screens.

Copied by permission from Messrs. Lumière's Pamphlet.

(4) The camera (C), to the lens of which is fitted the Auto P.O. screen.

(5) A background (F) completes the installation. M indicates the position of the sitter.

§ 72—25. **Lantern Projection in Natural Colours.** This can readily be done with any of the colour positives, made by the Sanger-Shepherd, Carbon, or Pinatype processes. The Dufay, Omnicolore, and Thames Colour Plates lend themselves admirably to projection, and can be used without further alteration, or if too large can be reduced by copying to the lantern size ($3\frac{1}{4}$ inches square). Autochrome positives are also

excellent, provided they are correctly exposed and developed, but as a rule they are too dense for projection purposes. In this case they should be reduced, either by one of the reversal solutions diluted with five or six volumes of water or by Farmer's method (for which see tables). If, however, the plates are fully exposed, or were slightly over-exposed and correctly developed, they should be quite thin enough. But with these plates lime or arc light should always be used. Autochromes are often considerably improved by intensification, even if the colours seem bright enough when viewed by transmitted light, because the enormous magnification reduces the brilliancy of the original very considerably.

In order to prevent the film from melting or cracking by the heat of the light, it is well to soak the positive in chrome alum or Von Hübl's solution. It is doubtful whether varnishing is any protection at all. In any case it is as well to place one or two sheets of mica immediately in front of the condenser, if you cannot use an alum trough. (See Appendix 17.)

§ 73—26. **Re-sensitising Colour-screen Plates.**—If a packet of plates happens to be stale, or if it is desired to increase the sensitiveness of a plate, it may be revived in the following way.

Make up the following solution :—

Alkaline solution of Pinachrome 1 : 500 . . .	2 c.c.
Absolute alcohol (96 per cent.)	50 ,,
Distilled water	200 ,,

Immerse the plates for two minutes in the bath in absolute darkness, or faint green light. Dry rapidly,

preferably on a whirler, or in front of an electric fan. If neither of these is at hand, shake the plate rapidly to and fro for five minutes. If this be not done, the alcohol is apt to soak through the plate and dissolve the Methyl Green, or else the plate may become fogged. As the result of this treatment the reds become rather too pronounced, and the greys become a little too warm in tone, but in every other respect the plate will resemble a fresh one. By this means the plate will be rendered three or four times more sensitive. The red tone may be got rid of by using a Dufay screen instead of an ordinary Autochrome one, since it is a purer yellow than the latter, and gives a slightly colder tone, thus correcting the excess of red which is just what is wanted in this case.

Mr. T. H. Grant re-sensitises in the following way. He makes a drying cupboard out of a light-tight box of sufficient size to contain four plates resting against the sides, and to allow a small box containing calcium chloride, having a perforated lid, to be placed in the centre, so as to dry rapidly the plates. A 7×5 porcelain dish to contain the sensitiser, some absorbent blotting paper, and a whirler or electric fan complete the outfit.

Prepare the following solutions. For a half plate mix 30 c.c. of alcohol (90 strength) with 90 c.c. of distilled water, thus reducing the strength to $22\frac{1}{2}$ degrees. To 80 parts of this add 10 parts of ammonia solution and 10 parts of the dye solution as supplied by Mr. Charles Simmen (to be obtained from Mr. Grant, of the Lumière Co., 89, Great Russell Street, W.C.). The plates are now immersed in the bath for four minutes

in complete darkness, the time being ascertained by an alarm clock, or a watch, observed by a screened-off dark-room lamp. The dish should be rocked, and the plates placed on end in total darkness to drain. They are then whirled or fanned, and afterwards placed in the drying-box with the calcium chloride until the morning. To hasten matters, one plate can be whirled while another plate is soaking in the dish. Such plates will retain their sensitivity for at least a month after being treated. Mr. Grant says that with these plates he can get good results with an exposure of $\frac{1}{16}$ second at F/5, or $\frac{1}{30}$ second at F/4. (See Appendix 18.)

§ 74—27. **Preparing Light Filters for Colour Photography** (von Hübl).—For a normal Autochrome filter make the following solutions:—

Nelson's gelatine 1 : 10 . . .	40 c.c.
Rapid filter yellow 1 : 10 . .	12 ,,
Echt Rot 1 : 10	14 ,,

For use take 7 c.c. of the dyed gelatine for each square decimetre of the glass to be coated.

To correct the predominant blueness of neutral tones in the shadows, and especially snow scenes in sunshine, and in all cases in which insufficient exposure is unavoidable, or on dull, cloudy days, use a filter made according to the following formula:—

Gelatine solution 1 : 10 . . .	40 c.c.
Rapid filter yellow 1 : 10 . .	14 ,,
Echt Rot 1 : 2000	14 ,,

The starch grains of the Autochrome, or even the discs and squares of most of the other screen-plates,

are not noticed when the lantern screen is more than 10 or 12 feet from the spectator.

A fine natural-colour slide is a remarkably realistic and beautiful object when projected, and is admirably suited for educational purposes, and making medical records. Butterflies, flowers, portraits, and views with plenty of colour in them, are charming subjects and always command the applause of the spectators.

§ 75. **Stereoscopic Effect of Colour Pictures.**—I have repeatedly observed that colour slides show a marked stereoscopic effect when projected on the sheet, and many of my friends have remarked the same thing. It is needless to add that it is not a real stereoscopic projection, although the illusion is often very striking.

§ 76. **Colour Screen Filters for Monochromatic Light.**—These may consist of (1) Pieces of coloured glass; (2) stained gelatine, either separate or coated on glass, and protected by a second piece of glass, as used for the Autochrome plate; or (3) thin glass troughs with parallel sides, containing the coloured fluid and hermetically sealed.

Most of the following substances or solutions have been recommended by Professor R. W. Wood. They correspond to the chief colours of the spectrum, and ultra-violet and infra-red rays, and will be found to afford very effective monochromatic light filters for Microphotography and laboratory work when using the Mercury vapour lamps.

Ultra-violet light (line 316 to 326) is produced by a chemically deposited film of silver on a quartz lens or plate. This filter lens was employed by Wood when photographing the moon and landscapes by ultra-violet

light. The silver film should be of such thickness that a window in front of a brilliantly lighted sky is barely visible through it.

Ultra-violet light (line 365) is obtained by a very dilute solution of methyl violet 4 R (Berlin Anilin Fabrik) and nitroso-dimethyl aniline.

Deep violet (line 405) may be made with Methyl violet and Chinin sulphate in separate solutions.

Blue violet (corresponding to the primary colour). Ammoniated saturated solution of Sulphate of Copper; a solution of Sulphocyanate of Cobalt.

Blue (line 436). Cobalt glass (thick) and Æsculine solution.

Green. Solution of bichromate of potash and a solution of Neodymium chloride. The Bichromate transmits the Green and the two yellow lines. The Neodymium absorbs the Yellow, leaving the Green.

Green (another line 492). A mixture of Guinea green (B extra) and Chinine sulphate.

Yellow (line 579). A thick layer of Bichromate of Potash; or (2) a solution of Eosin and Chrysoidin.

Deep red (line 690). Very dense Cobalt glass and a layer 1–2 cms. thick of saturated solution of Potassium Bichromate. This was used by Wood for photographing infra-red landscapes. A clear blue sky is nearly black through it, and sunlit foliage comes out nearly white.

Infra-red. Saturated solution of Iodine in Bisulphate of Carbon. It is quite opaque to the eye and all visible rays, but freely transmits the infra-red rays.

A good monochromatic light can be obtained by saturating an asbestos cylinder with a strong solution

of Chloride of Lithium. A good green light may be obtained by placing a bead of fused metallic thallium in a loop of platinum wire in the extreme outer edge of the flame.

For most work, the Mercury Arc will be found very satisfactory. (For further details see Appendix 19, p. 285.)

CHAPTER IX

THREE-PLATE AND TWO-PLATE COLOUR PHOTOGRAPHY

§ 77. The Theory of Three-colour Photography. —The process of M. Lippmann is of scientific interest merely; comparatively few workers have attained much success with it, and it is only to a very limited degree suitable for exhibition purposes. Those processes, however, which depend on the "three-colour" principle are daily growing in favour, many of the positives being of great beauty. There are two forms of this process, the "subtractive" one which is worked by Sanger-Shepherd & Co., and the "additive" method, of which the Lumière Autochrome, the Omnicolore, and the Thames plates are excellent examples.

The principle of three colours being used to reproduce all colours was discovered independently by Fredk. Ives,[1] of Philadelphia (the inventor of the "Half-tone" process, which has revolutionised the art of illustration of books and newspapers), and Ducos du Hauron, of France. It is founded on the Young-Helmholtz theory of colour vision, elaborated by Clerk Maxwell. As this theory is of fundamental importance, a certain amount of repetition will be pardoned. Every colour in nature

[1] One of my critics in "Knowledge" (Feb. 1911) denies this statement, but further investigation of the subject only confirms what I have stated, viz. that he discovered it independently.

can be formed from one or more of the three primary colours (or, more strictly speaking, coloured lights), red, green, and blue-violet. Thus, orange-red light and green light, when combined, produce the sensation of yellow; green and blue, that of greenish-blue, orange-red and blue, purple; while brown may be produced by the admixture of much red, a little green, and less blue. The different shades of these coloured lights may be produced by varying the intensities of the mixtures.

A mixture of all three coloured lights in the right proportion will produce the sensation of white. On the other hand, the superposition of the same colours in the form of pigments will produce the sensation of black, since when combined each pigment absorbs the colour which otherwise would be reflected by the other pigment; hence no colour is reflected and the result is black.

Ives devised a camera having two reflecting mirrors by which three negatives of the same object were simultaneously obtained—one behind an orange glass or filter, one behind a green glass or filter, and one behind a blue-violet glass or filter. In a later form of camera the stereoscopic principle was employed, and the three pairs of positives were viewed in a stereoscope which he called a Kromskop.

§ 78. **Ives' Kromskop.**—By using a triple lantern Ives superimposed the three coloured images on a sheet. Now, although true stereoscopic pictures in relief cannot thus be obtained, since one cannot combine stereoscopic images on a screen as is done in the Kromskop, an apparent plastic relief not observed in

black and white slides is obtained. I have heard this remarked by many people. The effect is even more pronounced when the picture is observed with one eye only. Possibly the explanation lies in the fact that the colour increases the sense of reality in the picture and enables the mind to supply the plasticity which experience tells us must exist in the actual object. This is only carrying a step further the well-known fact that if we look with one eye through a short tube at an engraving or painting, it will convey a sense of plasticity which is wanting when the same picture is regarded by both eyes.

Fig. 21 shows the essential parts of Ives' Kromskop. A, B, and C are sheets of red, blue, and green glass

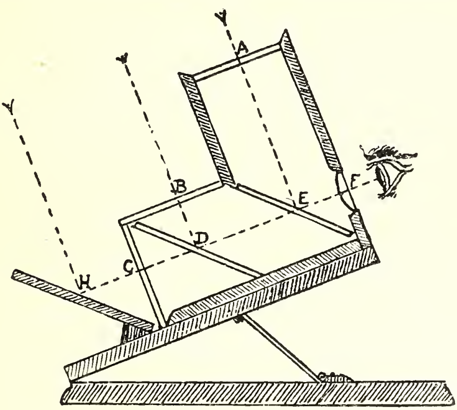


Fig. 21.—Ives' Kromskop, showing how the pictures are combined.

respectively, on which the three pairs of stereoscopic positives made for these colours are placed. H, D,

and E are mirrors inclined at 45°. F is one of a pair of stereoscopic lenses, *i.e.* of two convex prism lenses, the prisms having their bases directed outwards, and the lenses are each of slightly longer focus than the distance CF.

The mirrors and glass plates are so arranged with respect to F that the distances AE + EF, BD + DF, and CF are all equal, so that the images of each colour enlarged by the lenses FF will exactly coincide, and give rise to a single coloured aerial image in stereoscopic relief at the near point of the observer. This coloured image appears to stand out in the most vivid relief, and if the three positives are equally illuminated by an even light, by means of a fine ground glass placed in contact with the outer side of the three pairs of positives, and the colours correctly chosen, the result is exceedingly beautiful.

A difficulty arose in connection with the two mirrors marked D and E which Ives overcame in a most ingenious manner. It was necessary that they should be unsilvered, since they had to transmit light, and unsilvered mirrors give at least two images—one from the front surface, and a second, not so bright, from the back surface. The difficulty was overcome by using for each mirror a coloured glass which absorbed the kind of light which entered it and would otherwise have been reflected. For example, the mirror E had to reflect red light from the red transparency A; so to quench the red light that entered it, it was made of a blue-green pot-metal glass that absorbed red light, *i.e.* one in which the colouring matter is spread throughout the substance of the glass, this being

more effective for the purpose than a flashed one. The only light reflected from E was the red light which was reflected at the first surface. Similarly the mirror D was made of chromium green glass which absorbed the blue from the blue positive B. On the other hand, the glass D was transparent to the green light from G, while the glass E transmitted the light from both the green and the blue transparencies.

§ 79. **Colour Filters.**—In order to make negatives for reproduction by an additive method such as Ives' Kromskop or by any of the subtractive ones to be described, it is necessary to use colour filters in order to ensure that only the light actually wanted shall be recorded on the photographic plate. The colour filter is understood to mean the coloured glass or gelatine film placed in the path of the rays to exert a selective action on the light which falls on the photographic plate. The colour screen is a plate covered with coloured dots, grains, or lines, and is placed immediately in front of the panchromatic film. Neither "pot-metal" nor "flashed" coloured glasses are suitable as colour filters, because they absorb too much light and the colours do not admit of adjustment, nor can coloured glass of the requisite quality always be obtained. Gelatine films stained with aniline dyes are now generally employed, and these are usually sealed in between two pieces of glass. The great number and variety of such dyes admits of almost any desired absorption being obtained. Some few workers prefer to use the unprotected film only, and to place it in the diaphragm slot of the lens fixed on a Waterhouse stop. Such an unprotected film

is very liable to damage, and it is more usual to seal it between glasses with canada balsam and to bake the filter at a gentle heat for some days in order to make the balsam set.

The glass that is used for this purpose has to be plane and optically worked, or the definition of the image may be impaired. While it is quite true that the use of such glass plates introduces a slight elongation of the focal length, it is generally even safer to employ thick glasses than thin ones, for thin filters are very liable to distortion, which renders them useless. Care should always be taken that the filters are not held too tightly in their rings.

The position of the filter is a matter of some import-

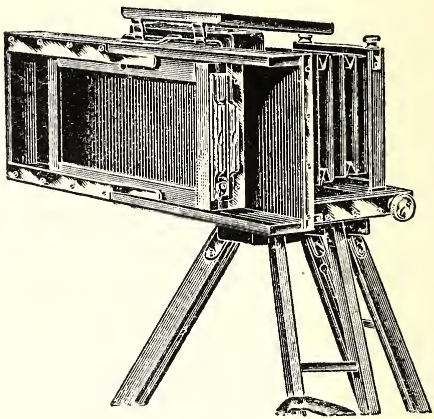


FIG. 22.—Sanger-Shepherd's Three-colour Plate Camera.

ance. Unless a special camera is used, it is generally most convenient to fix it on the hood of the lens. In

this position the light has some distance to travel after passing through it, and therefore it must be made of good quality glass. On the other hand, the filters may be of the same size as the photographic plates, and fitted immediately over these as in the camera depicted in Fig. 22. Here the optical quality of the glass is not of the same importance, but they must be very even in colour and have no bubbles or flaws, as shadows of these would be reproduced in the image.

It is always advisable to focus the image through one of the filters, owing to the shift in the position of the image produced by the filter, considered as a plate of glass and quite apart from its absorption effects. There are two effects produced by a plate of glass under these conditions. The most obvious is the alteration in the focus. If the plate is placed behind the lens the image of a distant object is thrown back by an amount equal to $t\frac{\mu - 1}{\mu}$, where t is the thickness of the plate and μ its refractive index. This amount is approximately one-third the thickness of the plate, since μ is always about 1·5. The deviation of the light is indicated in Fig. 23. On the other hand, when the plate is in front of the lens there is no shift of the image or alteration of focus unless the object is near. The second effect of a plate of glass placed behind the lens is to produce a slight alteration

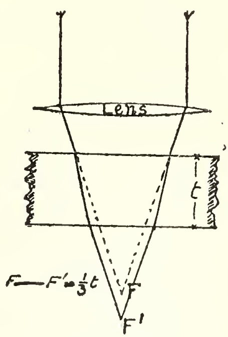


Fig. 23.

in the size of the image, and therefore it is important to see that all the filters of a set are of exactly the same thickness, as any variation in this respect will throw the images slightly out of register; a serious matter in large-sized pictures and process work.

§ 80. **The Testing of Colour-plate Filters.**—The test which is now usually applied to filters is to photograph a spectrum of white light through them. Negatives of a spectrum are made upon the plate to be used through each of the three filters, and from these it can be seen exactly what light is recorded. This method is also valuable, because it at once shows if any ultra-violet light is being passed by the filters. This cannot be seen by the eye, but the plate is very sensitive to it. The best filters now in use show under this test a slight overlap between the red and green filters in the yellow, and between the green and blue filters in the blue-green. There should be no unrecorded gaps.

Much may be learnt from a simple visual examination of the filters. If the red and green filters are superposed and a bright light is viewed through them, then a person of normal colour vision should see a dark yellow colour. The blue and green filters superposed should produce a dark bluish-green. Although the ultra-violet light cannot be seen, one can ascertain if the red filter passes any extreme violet by superposing the blue one upon it, when only a very deep red without any violet tinge should be seen. Any red filter that fails to pass this test is valueless.

§ 81. **Making Three-colour Negatives.**—When the light filters have been accurately chosen, a plate is exposed behind each filter in a camera. It might be

thought possible to take all three pictures at once by using a wide camera with three lenses, but this is impossible, because unless the three negatives are taken from exactly the same spot, the copies cannot be accurately superposed, since the difference in the point of view would give stereoscopic images which cannot be made to coincide. Each plate must receive such an exposure that a white object may be represented by a deposit identical in position and area in each of the three negatives. This forms the key to successful printing.

Sets of three-colour negatives may be made with an ordinary camera, provided that some simple holder is made to hold the filters one at a time in front of the lens. The operation consists simply in exposing three panchromatic plates behind the red, green, and blue filters successively, and then developing them in the ordinary way. It is most important that the correct exposure be given to each plate, so that a scale of greys is rendered in the same manner in all. To judge of this, trial exposures may be made on a piece of crumpled white blotting-paper, and the exposures altered until the images of it in the three negatives are identical.

A very convenient attachment to a camera for this class of work is a repeating back having a long dark slide to hold the three plates, or one long plate, and a frame holding the filters in front of it. The frame and the dark slide move along together, so that plate and filter are both changed by the one movement (Fig. 24).

§ 82. **Butler's Three-plate Camera.**—Mr. E. T. Butler has designed a useful camera on the principle of Ives' Kromskop. It will be found very useful for procuring the negatives for the Sanger-Shepherd method.

The camera is of the box form and fitted with grooves to hold three double-backs, two above and one behind (Fig. 24). The first sensitive plate, F, has a red filter in contact with it, the second, G, a blue filter, both made of patent plate, but the third sensitive plate, H, has none at all. In order that the light, after passing through the lens should reach the plates F and G two glass plate reflectors placed at 45° are required. Since

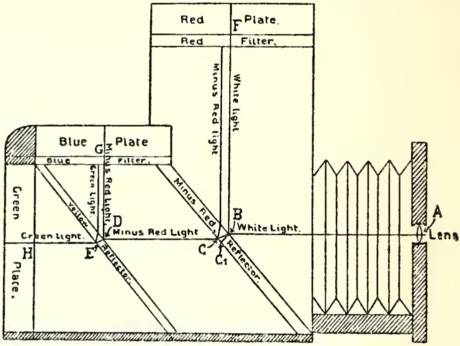


FIG. 24.—Diagram of path of light in Butler's Three-plate Camera.

both the front and back surfaces of a glass plate reflect light, it would give rise to double images, were it not in some way prevented. Ives got over the difficulty by employing thin wedge-shaped reflectors and covering their backs with coloured varnish. Butler has got over the double images by employing two reflectors set at an angle of 45° to the axis in the following ingenious way. The first reflector consists of bluish-green glass (the complementary to red) which absorbs the red

light and transmits the blue-violet and green rays only. Thus the white light after passing through the lens reaches the first plate and is partly reflected directly upwards, and partly reflected and partly refracted from the back surface of the plate. On undergoing a second refraction into air the ray passes up parallel to the main pencil. On reaching the red sheet placed immediately in front of the sensitive plate, the green and blue rays are absorbed while the red rays pass through, thus all the light reflected from the back of the plate is absorbed and never reaches the sensitive film at all.

In the same way the second reflector consists of yellow glass the complementary to the blue, so that the rays reflected from the back of this plate are absorbed by the blue filter and only the blue rays reach the second sensitive film. Thus, again, the rays reflected from the back of the plate become absorbed and never reach the film. The remainder of the light, which is green (since it has lost its red and blue constituents), passes directly on to the third panchromatic plate, and, of course, requires no filter in front.

The order of the three coloured filters must be so arranged that each will get its proper share of the light. Hence the red plate which requires a long exposure must have the greatest volume of light. It is therefore placed at F, so as to receive the full reflected beam of white light. The green filter is really in the brightest position, since it receives all the transmitted light. Since a red filter can be made which lets all the red through, but a green filter cannot be made to let all the green through, it has been found best to keep the green for the direct light. Of course, with this camera the

exposure is the same for all three negatives and cannot be varied as is the case with other cameras.

The negatives which receive reflected light, viz. the red and blue ones, will be reversed, whereas the green negative which receives direct rays will not be so. This may be rectified by turning the green negative film-side out, taking care to allow for the change of focus owing to the thickness of the glass support.

§ 83. **Two-plate Colour Photography.** — The difficulties attendant on three-colour photography, and especially on making all three exposures at one time, have led to attempts being made with two colours. Gurtner has invented and patented a very simple process, which, while ignoring the red element, still enables one to produce charming pictures of natural scenery. He first takes a chlorobromide emulsion plate, very thinly coated (in other words a lantern plate), stains—in the dark in a bath of naphthol orange, or aurantia, dissolved in water—dries it, and then places it in contact with a panchromatic plate, film to film. The two plates are then placed in the dark slide, taking care that the glass side of the lantern plate faces the lens. The ground glass is reversed, as is done when taking an autochrome picture in order to compensate for the thickness of the glass, and an exposure made in the ordinary way. The orange lantern-plate absorbs the blue rays, which act on the plate and form the image, and allows the red, yellow, and green rays to pass through the semi-transparent film. These act on the panchromatic film, and form a second image by the action of the red and orange-green rays. The orange plate, which has a dark image when the blue rays have acted, serves to

print the yellow image, while the panchromatic plate, which gives a dark image under the red-green rays, serves as the negative for the blue image. A little trouble is necessary to adjust the density of the orange stain so as to give the relatively correct exposures for the two plates. In fixing, the yellow stain dissolves out. A print is then obtained from the panchromatic plate, either by making a positive and staining it blue, or by making a blue print on a ferro-cyanide paper direct. A positive is made from the lantern plate (which has now lost its colour) either on a second lantern plate, or on a detachable celloidin paper. These copies are best fixed in ammonia, without being toned, and stained lemon or orange-yellow. The blue and yellow glass positives are now dried and placed in position, face to face; and bound together like a lantern slide with binding adhesive paper. If a paper print is required, the celloidin print is squeezed down on to the blue paper print, after careful adjustment.

The results of this process are often very satisfactory, and it has the advantage of simplicity, since any ordinary camera will suffice, no filters or dyes are needed, as is the case with three-colour processes; and only two prints need putting into register. The ferro-cyanide (blue-printing) paper can be obtained in packets from any dealer. It is very useful to judge the effect of a negative, as the prints are fixed in ordinary water, and are made in a minute.

CHAPTER X

THREE-PLATE PHOTOGRAPHIC COLOUR PRINTING

§ 84. **Colour Prints.**—The colour processes hitherto described only furnish single diapositives, *i.e.* transparencies in which the picture is illuminated from behind, and seen by one person at a time, or projected on to a screen. But people naturally call for pictures which can be hung up on a wall, or placed in an album, and seen by reflected light. Such pictures also should be capable of reproduction. These two problems are by no means so easy of solution as would appear at first sight, although there are quite a number of ways by which they may be accomplished. Some of these methods yield at best only poor results, while others require an amount of experience and care which is possessed by very few persons. The following processes, however, are quite successful in the hands of careful workers.

§ 85. **Practical Details for working the Three-Plate Method with Butler's Camera.**—Mr. Butler prefers Wratten and Wainwright's Panchromatic plates for all three negatives, or Wratten's Panchromatic plate for the red exposure, and the Gem "Tricol" for the green and blue. But any ordinary plate will do for the blue just as well.

Having inserted the three plates into the camera behind the three filters, as described in § 81, proceed

to judge the exposure by a Watkin's or Wynne's actinometer. If the paper changes until it matches the dark green sector in any time up to 45 seconds or even a minute, you can expose as the actinometer indicates; but if the time exceeds one minute, double the exposure. If it exceeds two minutes, multiply the exposure by three. Sunsets require from 5 seconds to 15 seconds, with an aperture of from F/4 to F/6.

Each colour is represented on each negative in varying densities of the silver images in the same way as if each plate were exposed separately, and of course each print must be made in the complementary colours to the filters through which the pictures were taken.

Method of Procedure.—Three negatives are first made in the camera:

No. 1 negative (the red),	making the	blue	print.
No. 2 negative (the green)	,,	red	,,
No. 3 negative (the blue)	,,	yellow	,,

No. 1 negative is taken direct, and a print made from it by contact will, of course, face the right way. It is placed in the enlarging apparatus (glass side to the lens), and the exposure is made in the usual way to make a positive. With daylight the ordinary actinometer tint must be used, which may be halved or doubled. Develop with Metol-Hydroquinone for the black tone lantern plate which is to record the enlarged positive. Develop until all details are out, but stop immediately the high lights begin to veil over. The positive will be thin, but quite strong enough if the details show up when the positive is placed on a white ground. Fix in Hypo, wash well in running water for a quarter of an hour, then place in an 8 per cent.

solution of Ferricyanide of Potassium (red prussiate) until bleached. Wash well for 5 minutes, then place in an 8 per cent. solution of Perchloride of Iron for one minute. Wash well for 30 seconds, then place in Hypo for one minute. Wash again in running water for 5 minutes. Place for a moment in a weak solution of Sulphuric Acid (a few drops to 8 ozs. of water) until the yellow stain is removed. Finally wash well for 3 minutes to get rid of the acid. This forms the positive from which the blue picture is obtained.

No. 2 negative (red printer) is placed in the enlarging apparatus, glass side to the lens, and a copy made on a black-tone lantern plate, as was done in the case of No. 1 negative.

No. 3 negative (yellow printer) is placed glass side to the lens as before, and similarly treated.

No. 2 and No. 3 are developed for 5 minutes to form the positives, so as to give good printing density. Fix, wash, and dry, and use for printing the positives. Printing plates are now made from these three lantern plates by the Pinatype method (*q.v.*) by sensitising gelatine-coated plates in a solution of 1·25 per cent. of Potassium Bichromate.

Printing the Plates.—These sensitised plates are first dried in the dark, and are then placed, film to film, with the No. 2 and No. 3 lantern plate positives, and exposed to light. The time of exposure is best judged by means of an "Akuret" actinometer. One piece of ordinary P.O.P. paper is placed in the "Akuret" (in No. 9 for the red, and in No. 12 for the yellow. When No. 9 is nearly black No. 2 plate will be almost rightly printed, and when No. 12 is nearly black No. 3

plate will be right. After washing out the sensitiser, dissolve out the silver with Farmer's Reducer, wash well and place No. 2 printer in the pinatype red dye, and No. 3 printer in the pinatype yellow dye. The free dye is now to be well washed out of the print plate with running water, and then the printing paper is applied (red preferably first). The time of soaking in the dye-bath depends largely on the depth of printing. For the red plate take about 5 or 15 minutes. Examine and wash off the free dye until a vigorous image is made. If necessary, the plate may be re-dyed. The yellow should be examined after one or two minutes, so as not to overdo it. It may, however, take 10 or 15 minutes. (The yellow image will be barely perceptible.)

If the Pinatype method be adopted for the red and yellow, place the print plates in contact with the Pinatype transfer paper, first with the red print plate, and then with the yellow one, being careful to keep them in register.

If a P.O.P. print is to form the base, the red print must be brought in contact with the P.O.P. image—it can be seen through the back of the print plate. When in register, squeegee and allow it to stand, usually for about five minutes, but you may judge by turning up the corner. The yellow print is transferred in the same way. This also takes about five minutes. The enlarged negative from which the P.O.P. print is made by contact may be formed as follows:—A positive is made by contact with No. 3 negative, and placed in the enlarging apparatus (glass side to the lens), and a black-tone lantern plate exposed in the usual way.

This paper negative should be rather smaller than the positives, so as to allow for the expansion of the paper when wet. By always using the same make of paper, the amount of expansion can be readily judged. With Gem Dry-plate Co.'s P.O.P. paper, the necessary alteration can be secured by advancing the plate $\frac{1}{8}$ inch nearer the lens than the position in which all the positives are taken, and at the end of the enlarger place the smaller positive $\frac{1}{16}$ inch further from the lens.

The red-yellow print, prepared as already described, must now be brought in contact with the converted blue plate. The register can readily be seen through the back. If the balance of colour is correct, squeegee, and when dry, the picture may be viewed through the back of the blue glass. The plate may now either remain in contact with the print, or the print may be stripped off, leaving the bare glass—provided, of course, that the converted blue plate has been taken on a stripping plate, the glass of which has been prepared before coating with the emulsion. These plates can be bought at any of the large houses.[1]

§ 86. **Three-colour Half-tone Process.**—It is in photo-mechanical processes that three-colour work has found its greatest application, and that chiefly in the half-tone process. Large numbers of colour prints are now executed in this manner. The colour plates in this book may be taken as examples, and if they are

[1] This description has been almost entirely taken from Mr. E. T. Butler's paper read before the Society of Colour Photographers on January 26, 1911, and introduced here by his kind permission. He supplies the apparatus direct from his address, see Table 26, Appendix.

examined with a magnifying glass, it will be found that they consist of dots of the same three printing colours (yellow, magenta pink, and cyan-blue) as are used in the other "subtractive" process described elsewhere. The use of half-tone printing in this connection has the great advantage, that once the printing blocks are prepared, a practically unlimited number of prints may be obtained. The preparation of these blocks, however, involves the comparatively complicated process of half-tone block making.

As it was originally worked, the process consisted in first preparing the usual three negatives of the subject through the colour filters, exactly as has been described for other methods; then from these negatives three transparent positives were made on ordinary photographic plates. From this point the operations become those of preparing half-tone blocks, for the positives are each in turn illuminated from behind, and a half-tone screen negative is made from each. In the making of these negatives a transparent screen with two series of ruled opaque lines crossing each other at right angles is placed in front of the photographic plate, when the varying tones of the positives become translated in the negative into dots of varying sizes. This screen must not be confounded with the "colour screens" described in Ch. VIII. and IX. Such negatives are printed on to copper or zinc plates coated with a thin film of bichromated fish-glue, and then washed in cold water. This dissolves away all the still soluble gelatine unaffected by the light, leaving a positive print in insoluble glue which, after being heated to harden it, acts as a resist to the etching liquid with which the plate

is afterwards treated. The etched metal plate when mounted on wood or metal, "type high," is called a "block," and has innumerable dots of varying sizes standing up to a common level. This can be printed like type on an ordinary printing press.

This form of the process is still in use for much work that has to be photographed away from the studio—for copying pictures in galleries, for instance—but by employing either fine-grained dry-plates or collodion emulsion, and having the colour filter and the half-tone screen both in position at the same time, the colour negative can also become a "screen" negative, and thus the number of photographic operations may be reduced. By whichever method the three blocks are produced, they are printed in succession on smooth surfaced paper, superposed in absolute register, the order being usually the yellow first, then the red, and lastly the blue. The yellow ink, being the most opaque, is printed first, and the blue, the most transparent, last, as any slight opacity in the second or third printings would tend to obscure the effect of the inks underneath. All "subtractive" methods are somewhat at a disadvantage compared with screen-plate and other additive methods with regard to their reproduction colours. While there is no great difficulty in obtaining the correct red, green, and blue for "screen" plates, it is, however, still impossible to procure quite the right cyan-blue, magenta-pink, and yellow for any of the subtractive methods, and the three-colour half-tone process suffers most from this drawback. The cyan-blue ink is usually the most defective; it rarely absorbs all the red light which it should do, while its reflection of

green light is never all that could be desired. The magenta-pink ink does not reflect sufficient blue and violet light. The yellow ink is fairly satisfactory. As a result, many colours are incorrectly rendered, greens are too dark, purples and greys too red, and reds often too orange, and the correct hues have to be recovered by locally etching the blocks; "fine etching" as it is called.

In spite of this disadvantage great strides have been made with the process, and much good work is done by it. The comparative inexpensiveness of half-tone printing is also greatly in its favour.

§ 87.—**Collotype Colour Process.**—Collotype is a printing process similar in many respects to lithographic printing. The prints are obtained in printer's ink from a reticulated gelatine surface. Sheets of thick plate glass are coated very thinly with a solution of gelatine and bichromate of potash. These are dried level in an oven or large heated drying-box, at a temperature too high to allow the emulsion to set. When cool they are exposed under the negatives, and are afterwards washed in cold water until the bichromate is entirely removed. The sheets of plate glass are then stood up to dry. When dry the image, looking similar to a steel engraving before it is inked up, can be seen on the plate. The plate is then soaked in glycerine and water, and this is termed in the trade "etching" it. After about half an hour's soaking the solution is mopped off with a dry cloth.

It is easy to understand how the glycerine solution will penetrate freely through the soft high lights of the image, while the shadows and half tones, hardened by

the action of light on the bichromate, absorb it less readily, or not at all, in proportion to the amount of light received, so that the image consists of varying degrees of moisture and dryness. When the inked (lithographic) roller is passed over the surface, the greasy ink adheres freely to the dry shadows, but is refused by the moistened high lights. The reticulation of the gelatine surface gives an extremely fine grain over the plate, invisible to the naked eye.

This method of printing can be done on almost any variety of paper suitable for general printing, and has the great advantage over half-tone printing blocks etched upon copper, or other metal, in that an artificially coated paper with a polished surface is not essential for the best results. The printing is done on a "scraper" press, not unlike a lithographic press.

Since a print can be taken in this way with a lithographic ink of any colour, all that is required will be to make three collotype plates from the three negatives in the way already described; then to ink each of them over with one of the three complementary printing colours, and finally to take a print on a single sheet of paper from all three plates successively, taking care that the three impressions lie in exact superposition.

In practice two main and several minor difficulties arise. In any process of three-colour printing the balance of the respective printings must be perfectly maintained in all the prints taken. Collotype plates are peculiarly liable to variation with changes in humidity; so that care has to be exercised to prevent the weather from affecting the conditions of the printing room.

The variable climate of England can scarcely be said to favour the process. Then from its very nature there is but little opportunity of doing any local work on the plates to remedy defects, so that it is very necessary that both filters and inks should be as perfect as possible, and whatever adjustments appear to be requisite must be done on the negative before making the print on the chromated gelatine. The inks of the primary colours also do not work so kindly on the rollers as does black ink, and therefore it is difficult to print evenly with them. The yellow tends to clog up the shadows. The red is too greasy and gives harsh contrasts. The blue is fairly easy to work with.

The other difficulty is fundamental. We refer to the superposing of the whole image of each colour. Of course, each of the three negatives must have been correctly exposed, but even then the yellow if printed first is apt to be overwhelmed, and the blue on the top will have become unduly prominent.

Moreover, considerable experience is necessary in order to obtain perfect uniformity when any considerable number of copies are being printed. It is often desirable to print a fourth impression made from a collotype plate obtained from a fourth negative, or sometimes the " yellow " plate is reprinted in a soft grey.

In spite of its difficulty, some very fine work has been recently done in colour by this process, and it has an assured future in connection with colour photography.

§ 88. **Sanger-Shepherd's Imbibition Process.**—This is a practical method. fairly casy of application, and

somewhat resembles his method for making transparency pictures. Three negatives are first taken through the colour filters, as has been already mentioned. The positives from them are printed upon a special celluloid film coated with gelatine containing bromide of silver, sensitised by immersion in the sensitising bath of potassium bichromate for three minutes and dried in the dark room.

The prints are made upon the film by printing through the celluloid—the celluloid side being placed in contact with the film side of the negative and exposed to daylight until, on examination in weak light, all the details are visible on the film as a brownish-yellow print, very similar in appearance to an undeveloped platinotype print. The printed film is immersed in warm water, and in a few minutes the unaltered gelatine dissolves away, leaving a perfect white image full of detail attached to the celluloid base. The print is next fixed in ordinary clean hyposulphite of soda solution until the white bromide of silver dissolves, leaving a transparent, low relief in clear gelatine. After washing in water for ten minutes, the prints are ready for staining up. The print from the green filter negative is stained up in the pink bath, and the print from the blue-violet filter negative is stained up in the yellow bath—the staining being stopped as soon as the two prints, when held over the greenish-blue print, give neutral tints in the grey shadows of the picture. Should one of the positives be accidentally overstained it may easily be reduced by merely soaking in clean water. They are then successively squeegeed on to a piece of paper coated with a thin layer of gelatine.

This absorbs the dye from the relief surface of the hardened gelatine. The gelatinised paper is first well soaked in water and spread over a glass plate, coated side uppermost. Then the pink-dyed positive (from the negative taken through the green screen) is squeegeed on to the gelatine paper until the whole of the colour has been taken up by it. In the same way the yellow-dyed positive (from the negative taken through the blue screen) is carefully adjusted in register on to the pink impression, and squeegeed down on to it. Lastly, the blue-dyed positive is squeegeed on to the pink and yellow image, which is kept wet to get an even impression. If any one of the colours is too weak, the printing plate for that colour may be re-dyed and used again. Thus a paper print is obtained on which an image built up of three colours is impressed. This may be squeegeed on to ground glass or polished glass, according as to whether a matt or glossy surface is desired. The print is now finished, and if the process has been correctly carried out, especially the correct exposures in the first instance, the result will be an extremely charming effect of colour. The skies are often very fine, indeed, much superior to autochromes, as the proper rendering of the sky is the chief defect in the starch-grain method. According to Sanger-Shepherd, the following are the chief sources of failure, with their remedies :—

The printing plates are liable to stick to the paper, because the paper has not been soaked long enough before use. It should be soaked in clean, cold water for at least ten minutes.

The printing plates take up the colour all over when

immersed in the colour bath. This is owing to an over-printed relief; the relief must be thin. The best results are obtained by slow development in water at 100° F. to 105° F. It is because of the necessity for using a very low relief that a thin negative is recommended.

Dark, muddy prints.—This arises from printing plates being stained too deeply, or from the relief being over-printed.

Blurred prints.—This fault is due to the paper being too wet, or because too long time has been taken in the transfer, owing to an unsuitable relief. With a correctly printed relief the whole of the ink should be transferred to the gelatinised paper within five minutes. The finished print should be at once pressed, surface dry, between clean blotters, and pinned up to dry in a current of air.

Full detailed instructions are sent out by Sanger-Shepherd & Co., along with all the materials necessary for carrying out their process.

§ 89. **The Pinatype Process.**—This method, invented by Dr. E. König, has considerably grown in public favour of late, and is well able to hold its own among competitors. The process, like Sanger-Shepherd's, depends on the selective action of certain dyes on the gelatine. Thus, supposing the three gelatine bichromate printing plates have been prepared as in the last process, then the parts exposed to light will be hardened, the rest remaining soft. Now, it has been found that dyes may be classified thus—

1. Those (and they are the majority) which stain the whole surface, either uniformly or partly, by a

selective action; the dye being in some cases removed by the water, in other cases remaining fixed.

2. Those dyes which stain the hardened parts of the gelatine more than the unhardened parts, since they enter into composition with the hard (light-impressed) parts which contain oxides of chromium.

3. A few dyes exist which do not touch the hard gelatine, but stain the (unacted on) soft gelatine. Such stains are called pinatype colours, and they constitute the dyes used in this process.

It will thus be seen that the pinatype method is the reverse of the Sanger-Shepherd, since the latter depends on dyes which adhere to the raised hard gelatine and come off on to the paper.

Pinatype colours should possess the following properties:—

1. They must be fairly soluble in cold water.

2. They must stain the soft gelatine strongly, and hardly touch the hard parts.

3. They must be fixed dyes, and incapable of being washed out.

4. They must readily stain the paper brought in contact.

5. The picture must retain its detail and sharpness after drying, and must not suffer from prolonged washing.

6. Lastly, the colours must not be liable to fade.

Fortunately all these properties can be found among the red, yellow, and blue dyes.

It may also be noticed that since these dyes do not stain the light-impressed gelatine, but only the parts unacted on, the pinatype print will be a facsimile of

the original negative. In other words, the original negative taken through the colour-screen is reproduced by the printing plate exactly as in the Sanger-Shepherd process, but with this difference: By the latter method the print is made from the light-hardened gelatine which receives the dye, whereas by the pinatype process it is the unchanged gelatine which takes up and transfers the colour. In order, therefore, to make a positive print, our bichromated printing plate must be made from a transparency (diapositive), and not from a negative, as in the other method.

To sum up, the pinatype process consists of five stages.

1. *Making the Negatives.*—Three negatives of the subject are taken through their respective screens.

2. *Copying the Negatives.* — Three transparencies (diapositives) are made from the negatives on a fine-grain emulsion, such as is used for lantern slides. These can be made to any size, so that if an enlargement or reduced print be wanted, the diapositives can be made to the size required in the print. The qualities of a lantern slide are transparency, brilliancy, and contrast, but the pinatype diapositives should be soft, without any great amount of density anywhere. This quality can be readily obtained by giving a full exposure, and using a diluted developer.

3. *Transferring the Image to the Printing Plate.*—From the diapositives three printing plates are made. These are glass plates thinly coated with gelatine and sensitised in a $2\frac{1}{2}$ per cent. solution of bichromate of potash (15 grains to 2 oz. of water), dried in the dark (6 to 8 hours), and then successively exposed behind the

diapositives. Each plate should be marked B, R, or Y in the corner, to indicate the colour to be used. The sensitising solution must be kept cool (60° to 65° F.), and the time for each printing regulated by a photometer or actinometer (Warnerke's or Sanger-Shepherd's). It is about the same as for collodion P.O.P. The image appears faintly drawn on a yellow ground. The plates should be well washed until all the yellow has disappeared from the water. They are then dried, and are ready for use at any time.

4. *Dyeing the plates*.—Three baths are to be made. A blue bath of 10 tablets pinatype blue to 9 oz. of water for the plate from the red screen negative (immerse for 15 to 20 min.); a red bath of 10 tablets pinatype red to 1 drachm of ammonia ·880 and 9 oz. of water for the plate from the green negative (immerse for 10 to 15 min.); and a yellow bath 10 tablets of pinatype yellow to 7 oz. hot water (immerse for half an hour).

5. *Printing the picture on paper*.—A sheet of transfer paper is soaked in water until it expands no longer. It is then gently and evenly squeegeed down on to the blue-dyed plate, which is taken wet from the bath. A piece of oiled paper is laid over the print to enable the roller squeegee to run smoothly. The progress of the transfer of the colour to the print must be watched by turning up one of the corners from time to time. On an average about ten to fifteen minutes will suffice. The blue print is then removed and transferred to the red-dyed plate. In this case it is well to place a thin transparent sheet of celluloid between the two, and as soon as the two are in register, to hold the top of the

print firmly and slip the celluloid from underneath, and then to squeegee as before. This precaution is necessary to prevent the transfer of colour before register is secured. In the case of the yellow dye this is not necessary, as it acts more slowly.

Lastly, the print now dyed with blue and red is squeegeed down upon the yellow-dyed plate. The order is therefore Blue-red-yellow, but you may make it Red-blue-yellow, or even Blue-yellow-red, but only experience will teach you which is best for each case. If any of the prints have been dyed too deeply, the colour may be thinned down by squeegeeing them on to a piece of paper coated with gelatine until sufficient colour has been abstracted. In the same way an unfixed print which is too weak may be reinforced by squeegeeing it on to its printing plate. Retouching may be done on any of the wet prints with a brush soaked in the dye.

One great advantage of this process lies in the fact that the three impressions of colour are superposed on the single support, and not on separate gelatine layers which require to be accurately placed in register. The weakest part of the picture lies in the blues, which are apt to become too red owing to the varying effect of the green filter.

§ 90. **The Colour Carbon and other Processes.**—Many other beautiful and useful processes exist, such as the Rotary Co.'s Stripping Pigment Films, in which the printing is done through thin sheets of celluloid and each developed pigment image is in turn transferred to a piece of single transfer paper. The Hesekiel-Selle carbon process and the Perscheid screen

process may also be mentioned in this connection, but it is beyond the scope of this work to enter into details respecting them, since they are quite unsuitable for the amateur by reason of the apparatus and skill required.

§ 90A. **Raydex Colour Process.**—This is a new colour printing process which seems to be rapidly gaining in favour, as it is easy to work, reliable, and permanent. In brief, the process is as follows: Three separate negatives are made behind red, blue and green filters, respectively. From these negatives bromide prints are made which, when washed and fixed, are soaked in water and laid in contact with Raydex colour sheets of the complementary colours for twenty minutes. The colour sheets are now stripped off the bromide prints, and each is squeegeed on to a celluloid plate and immersed in hot water until the unacted-on colour is dissolved off. The three-colour prints are now dried, and then one is placed on a paper support under water and again dried when the colour picture on the support is stripped off. Then two of the prints are carefully placed in register under water, taken out and dried, and, finally, the third colour print is adjusted in register on the other two. The three prints now adherent are again dried and the celluloid stripped off. The finished picture is then trimmed and mounted, and can be framed and hung up on the wall. The initial outlay is comparatively small, since any ordinary camera and lens will suffice, although (as previously pointed out) an astigmat lens is preferable. The only provisos being that the camera should not be of the roll film type, and further, that the plate holders should be of the hinge type, and provided with springs if the filters are to be

placed in contact with the plate. A long slide carrying the three plates side by side is to be preferred, but double backs may be used, the slide being turned round for the second exposure, and a second slide employed for the third exposure. This process has the further advantage that a small camera may be used, since enlargements may be made from the original negatives and colour prints obtained from two to three times the size of the negatives. In a good light, all three exposures will only occupy about 12 to 15 seconds with a long slide, and a few seconds more with separate slides.

Details of the Process.— *The Negative.* — First, three negatives are made on panchromatic plates through three colour filters exactly as in the Sanger-Shepherd process (see p. 163). The filters may either be cut the size of the plates, and placed in the slide in contact with them, or they may be placed in holders and fitted to the lens in front or behind. Some photographers prefer coloured glass filters; others, thin filters made of dyed gelatine. Any of the panchromatic plates on the market will do. They should preferably be backed to avoid halation. These should be marked R, G, and B to correspond with the filters. As regards the time of exposure behind the "blue" plate, give with F/8 a quarter of the time that the paper of Watkin's or Wynne's meter takes to match the tint. Thus, if the Actinometer takes 10 secs. to turn dark, give about two and a half secs. Each box of Wratten's plates gives the ratio of the exposures for the three colours. All three plates should be developed in the same dish, and at the same time in deep Virida light.

The Bromide Prints.—From each of these negatives when fixed, washed and dried, a print is made on Raydex Bromide paper. Each should be marked R, G, B, in the corner, to correspond to the negatives taken under the red, green, and blue filters, and care should be taken to cut them all from the paper the same way of the grain, so as to secure equal expansion, and consequently correct register when soaked in water.

As soon as the papers are soaked, place them side by side in a clean porcelain dish, and develop with any good developer. The Raydex Company recommend their single solution developer, diluted 1 in 20. A weaker solution, 1 in 30 or 40, is slower, but allows of greater control. This weak solution is advisable in the case of beginners, as if development is too rapid a weak image will result. The prints must then be fixed in Hypo solution—an acid fixing bath is to be preferred—in which they should be left for at least ten minutes. They are then removed and thoroughly washed free of Hypo, and then dried for future use; or when half dry they may be placed on a chemically clean glass plate, which acts as a support—and a colour print made directly from them.

The Colour Prints.—While the bromide prints are half dry on their glass supports, cut three pieces off the Raydex colour sheets a quarter of an inch larger than the Bromide paper, prepare three Raydex transparent supports by rubbing over each support with a few drops of the wax solution with a soft rag, and then polish it off with a fresh clean rag, avoiding streaks. Take two porcelain dishes. Fill the larger one with clean water and place the smaller one

in front of you to sensitise the colour sheets in. Next place the three colour sheets in the water, and allow them to soak until they uncurl and flatten out, which they will do in a few moments, and then hang them up to drain. Or, if you prefer it, you may merely sponge over the backs of the colour sheets with a wet sponge, taking care not to touch the colour side. They will at once curl up, but will soon flatten down again.

Now proceed to develop the colour. Measure out one dram of each of No. 1 and No. 2 solutions and add to them an ounce of water. This will be sufficient to sensitise three quarter-plate sheets—or even three half-plate sheets with care. Immerse the colour sheets in the solution for about two minutes, moving them about all the time. Now take the bromide print marked R (made from the negative taken through the red screen) in the one hand, and in the other hand lift up the blue sheet from the bath, drain off the excess of solution and slide it over the bromide print still adherent to the glass support under the surface of the water in the larger dish, taking care that there is a margin of colour sheet all round the print. Withdraw the two sheets in contact, and rapidly squeegee the two sheets together so as to get rid of all bubbles, being careful not to shift the papers, as chemical action is going on all the time, and any movement will give rise to a double image. Next, dry the back of the top sheet with blotting paper, and strip both papers off together with a flat knife off the glass, and then dab the moisture off the other side. Then hang up the two sheets stuck together to dry. Leave the prints in

contact for twenty minutes so as to allow the bromide paper to become thoroughly bleached. Treat the other bromide prints in the same way, *i.e.* place the "green" Bromide print in contact with the red colour sheet, and the "blue" print in contact with the yellow colour sheet. Renew the water in the big dish the moment it becomes coloured. Hang up the three combined sheets which have been roughly dried for twenty minutes, when the action will be complete.

It is worth while pointing out that the bromide prints, after they have fulfilled their purpose, may be washed and redeveloped, and again used for a fresh set of prints. Now, take a celluloid sheet previously cleaned with benzole and coated with waxing solution. Strip one of the colour sheets off the bromide paper (this should require a slight pull to detach, and not come off too readily, or it will show that it had not been dried enough), and, after dipping it for a second in water, lower the centre of the colour sheet, face downwards, on to the waxed celluloid surface, and then smooth down the two ends. Squeegee it firmly in contact with the celluloid, using first a flat squeegee, so as to exclude all air bubbles. Then squeegee again, under blotting paper, with the roller squeegee, using several pieces of blotting paper, so as to dry the colour sheet as much as possible. Treat the two other sheets in the same way. Then proceed to develop.

This is done by placing the three sheets in a large dish of hot water at about 110° F. or 115° F. until the colours begin to ooze around the edge of the paper. Now strip off the paper support, and rock the plate in the water until all the superfluous, unacted colour is

dissolved off, and the high lights are quite clear and transparent. As soon as you are quite sure that all the unaffected colour is dissolved off, rinse in a fresh dish of *cold* water. If any colour remains and blocks out the high lights, pass a smooth, broad camel's hair brush over the surface, taking care that the brush is free from all traces of grit. Then stand the print up to dry.

Combining the Colour Positives.—Single Transfer.—We have now three prints—a blue, a red, and a green one—attached to three separate sheets of celluloid. These prints have now to be brought into register. Soak a piece of Raydex single transfer paper in water until it becomes soft. Dip the celluloid plate carrying the yellow-coloured image into water, and slide the image over the paper support. Remove it from the water, drain, and then squeegee into contact, using a roller squeegee with blotting paper between. Brush over the blue and red positives with a little Raydex combining solution with a broad camel's hair brush. Leave them to dry on a flat surface out of the dust. As soon as the yellow positive is quite dry, strip it off the support, which can be readily done by bending it slightly. Then remove all traces of wax by gently rubbing the surface with a soft rag moistened with benzole. Soak in water along with the blue positive, and roughly register them under the water. Then remove and lightly squeegee, and slide the print until the two are in perfect register, avoiding all pressure, so as to prevent the two surfaces from sticking and tearing until they are precisely in apposition. Allow them to dry thoroughly, and detach the two prints,

now firmly adherent, from the celluloid. Rub with benzole, and apply the red print in the same way. When the final celluloid support is detached, the picture will have a fine polished surface. If a mat surface is desired, clean the surface with a soft handkerchief dipped in benzole, and then dip the print in water for a moment and allow the picture to dry quite flat. The picture is now ready to be trimmed and mounted.

The picture will be found to be reversed as regards right and left. This is immaterial for many subjects, such as flowers and similar objects, but whenever it is imperative that the picture should be the right way round as seen by the eye, the original negatives must either be taken with the glass side of the plate facing the lens, or the double transfer method must be used.

Double Transfer Method.—Soak a piece of Raydex temporary paper support in water for a few minutes, and apply it to the blue or red positive as previously described. In this method the yellow image must be laid on last, and the combining solution should be brushed over the last two images to be superimposed. As soon as all three colour positives are on the temporary support, clean with benzole, and soak in water at about 62° F. for a minute along with a piece of Raydex final support a trifle larger than the picture. Now remove both in contact and squeegee, and place between sheets of blotting paper under a flat weight for ten minutes.

In order to remove the temporary support, float on the surface of a dish of water at about 120° F., avoiding air bubbles, taking care that the support is on the top and kept dry. After two or three minutes, turn

over so that the temporary support is on the top, and then submerge the whole under the water. Gently remove the temporary support, and wash off all the soluble gelatine. The picture is now ready to be trimmed and mounted.

If the beginner fails to get satisfactory results the Raydex Company state that they will be only too pleased to put him on the right road, and it will greatly facilitate matters if the prints are sent for inspection.

CHAPTER XI

COLOUR PRINTING FROM SINGLE-PLATE TRANSPARENCIES

§ 91. **Uto-color Printing from Single-Plate Transparencies.**—The reproduction of colour transparencies on to paper so that they can be framed on a wall, or pasted in an album, has until recently only been effected by making three separate glass negatives, or printing blocks, and then either superposing transfer films stained with the complementary colours, or by direct printing of these colours, as is done in the half-tone colour process. Such methods will be found described in Chapter X. Although copies of remarkable delicacy and beauty can be produced by these methods, they all require three separate negatives to be made, besides entailing a certain amount of apparatus coupled with a degree of delicate manipulation which can only be obtained by constant practice. Hence any method by which a colour transparency can be directly printed on a sheet of prepared paper would be a great desideratum. In fact, the difficulty of reproducing colour transparencies has been the main cause of the want of popularity of colour photography among amateurs.

This difficulty has at length been more or less overcome by the Bleach-out Process of colour printing, which, although very far from perfect, is daily being improved upon. It has at length reached such

a stage, that, with a suitable colour transparency, very effective and faithful copies on paper are reputed to have been obtained in Europe.

We will now proceed to describe the methods and the principles on which it is founded.

§ 92. **The Theory of the Bleach-out Process.**—It is well known to everybody that the colours of wood and textiles change under the prolonged action of light. Wall-papers, carpets, watercolour paintings, etc., all tend to lose the brightness of their colours, and partially bleach-out in sunlight. Most colouring matters (dyes) when added to fabrics are not permanent. They tend to fade, and are for the most part removable by washing. A few dyes like Indigo and Safflower immediately impart a permanent colour to any fabric when it is dipped or boiled in the dyeing vat. Hence they are called *substantive colours*. Most woollen goods, and to a certain extent silks, form a permanent compound with dyes, and require no further treatment; but the vast majority of stuffs require a special re-agent called a *mordant*, which will form an insoluble compound both with the fabric on the one hand and with the dye on the other. The colours which require such treatment are termed *adjective colours*.

Alum, Cream of Tartar, Tannin, and the oxides of Iron and Tin are the principal mordants employed.

The power of resisting the action of light varies enormously with different colouring substances, and their resistance depends very largely on the colour of the light which attacks them. It is by making use of these facts that we are able to place certain colours or pigments on to the paper which are affected by different

coloured lights, and at the same time are quite under control. Of course, it is easy enough to make a direct copy in almost any single colour, but it is a much more complicated problem to get the various colours to reproduce themselves on the same sheet of paper by selective action of the light. The direction in which the solution of the problem may be sought for appears to lie in the bleaching-out process.

In order to understand the theory, we may as well begin by explaining what is meant by a pigment. A pigment is a colouring matter or fluid which permits a portion of the rays of white light to pass through it and absorb the rest. If a pigment in a fluid state such as water or oil paint, or aniline dye, be spread over a sheet of white paper, a certain portion of the light will pass through the layer to the white paper, and after being reflected will again pass through the coloured layer, and give rise to the sensation of colour in the layer in question. If only a small amount of light can pass through to the white paper, it is called an *opaque colour*. Such, for example, are Chinese White and Naples Yellow. Such a colour is said to have *body*, and is called a *body colour*, or opaque colour, because it hides the colours beneath it. If a large quantity of light passes through, it is called a *transparent* colour, of which most of the aniline dyes, the Umbers and Siennas, are examples. They allow the subjacent colours to shine through, or merely modify them. Colours made luminous by transmitted light, such as coloured glasses, and the stained glasses used for windows, as well as the colours of the spectrum, are all good examples of transparent colours.

§ 93. **Permanent and Fugitive Colours.**—When white or coloured light-rays are absorbed, they may either be changed into heat, without altering the composition of the pigment, in which case they are called *permanent or fast colours;* or the light-rays may alter or split up the molecules of the colouring matter, in which case the colour will be altered, or may even entirely disappear. These pigments are called *sensitive or fugitive colouring matters.*

If the rays of light which fall on the surface of a body are scattered diffusely, such a surface will appear white, and we call the body a white one. Snow, milk, lime, white lead, all reflect light diffusely, and therefore convey the sensation of white; but if a surface reflect light regularly, so as to form an image, it no longer appears white, but constitutes a mirror, and will have a metallic lustre. The surface of still water, glass, quicksilver, polished metals are familiar examples of what we mean.

If, on the other hand, the rays of light are nearly all absorbed, little or no light is reflected, and the surface of the body appears black. As we have already explained, no substance is absolutely white or black, since the whitest body known, viz. fresh fallen snow, only reflects about 85 per cent. or 90 per cent. of the light, and the blackest material, such as black velvet, powdered charcoal or soot, reflects about 1 per cent. of the light.

Grothus, writing in 1819, first explained the theory of the action of light on coloured bodies. He says, "Coloured light seeks to destroy in bodies upon which it acts those colours which are opposed to its own (*i.e.* complementary colours), while it endeavours to

retain its own or another analogous colour." Thus, red light would seek to discharge its complementary colour blue-green, while retaining the orange-yellow; and green light would discharge red, while retaining the green. In other words, a coloured body, whether it be a fast colour or one sensitive to light, is not affected by light of its own colour, since it either allows all rays of such light to pass through it, or else reflects them away. It is only the absorbed rays which decompose or destroy the colour. Now, a red coloured body does not absorb red rays, but it will absorb rays of other colours. If this coloured body is a fast colour, the only change observed, when other than red rays reach it, will be a rise of temperature, but if it is a body sensitive to light these rays will destroy the colour. And the same thing will happen in the case of any other colour. Hence we may formulate it in the following sentence, which Dr. J. H. Smith calls the Bleach-out Law:—

"A coloured body sensitive to light will only be affected by the light it absorbs, but not by the light of its own colour."

The rays which are absorbed cause a chemical change in the molecules of the sensitive colouring matter whereby the colour is destroyed. In other words, the colour bleaches out. Now, if we coat a sheet of white paper with a suitable gelatine emulsion containing a purple-red dye, and then superpose a yellow dye, and lastly a blue dye (taking care that these are the proper colours and in the right proportions), we shall obtain a black mixture. As a matter of fact, the result is rarely a pure black. It generally

has a greenish or greyish tinge, but a good black is what is aimed at, and with the increased experience which the manufacturers of printing-out colour papers are gradually obtaining, the colour is approaching nearer and nearer to an ideal black. Such a three-coloured emulsion layer on a white backing forms the basis of a printing-out colour paper.

The Effect of Coloured Lights on the Paper.—Let us suppose that a copy on paper is to be made of an Autochrome Transparency. Instead of a complicated landscape, let us, for the sake of simplicity, suppose that the transparency consists of six stripes or squares, A, B, C, D, E, F (Fig. 25), of the following colours: Black, Blue, Red, Green, Yellow, and White. A sheet of the sensitive pigment paper is placed in a printing frame with its colour (Black) surface in contact with the film side of a colour transparency (or with a piece of thin celluloid between the two in order to prevent the surfaces sticking), and then put in the sunlight. What happens is this. At A the Black stripe blocks out all the light, so that no action takes place, and the black surface of the paper remains unaltered.

At B the Blue stripe allows mainly the blue rays to pass through. According to the Bleach-out law, the Blue layer will be unaffected, since the Blue rays are not absorbed, but pass through it; but the light will be absorbed by the yellow and red pigments, and they will be destroyed and bleached out, so that ultimately when the action is completed, all the light which passes through the blue layer will reach the White surface of the paper, and be reflected through the Blue layer.

At C the Red stripe allows the Red light to penetrate

the Blue, Yellow, and Red pigments. The green light will only be absorbed to a small extent by the Blue pigment, since the blue and green waves overlap to a considerable extent, forming a greenish-blue or bluish-green mixture. For the same reason the green light will only act in a feeble manner on the Yellow pigment, because the Yellow and Green overlap, forming a greenish-yellow or yellowish-green mixture, according to the nearness of the waves to the red or the blue end of the spectrum respectively. But the green rays will bleach out the Red pigment almost entirely, so that we have a Yellow and a Blue layer left practically intact, and these two together make a green colour.

At E the Yellow stripe will permit Yellow rays to pass, and these will bleach out the Blue and the Red so that only the Yellow layer is left.

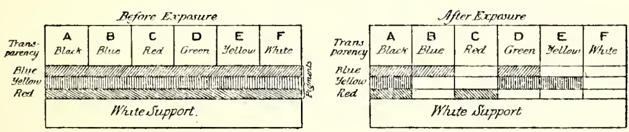


FIG. 25.—Diagram showing the action of light on the emulsion colour layer. Three separate colour layers are shown, as occurs in the Szczepanik paper, and not a single layer of mixed colours, as is the case in the Uto paper. This is done for the sake of clearness, but the action is identical in both papers.

At F we have a White or clear strip of glass left. In this case nearly all the rays which compose the whole spectrum pass through, so that all the three layers are acted upon. If they are all acted upon equally, they will all be bleached out together, and the

White of the paper will shine through the gelatine film unopposed, and the stripe will appear White. This White is formed by a subtractive process, *i.e.* by removal of all the superimposed colours, and its appearance is due to exactly the opposite process to the White seen in a diapositive (transparency), for in this latter case the White is formed by the combination of the three colours (additive process).

If, therefore, the pigments have been perfectly chosen, and have been acted on by the light so as to harmonise with the exact colours of the stripes, a perfect facsimile of the original ought to be produced. But, for obvious reasons, an exact copy can only be approximated, even with the most perfectly chosen pigments. For even if the pigments were right, it would always be impossible to regulate the light, so that the bleaching action can be stopped exactly at the right moment.

Up to the present time the writer has never once succeeded in getting a satisfactory print from any negative by this method. Perhaps the climate of S. Africa is unsuitable by reason of the extreme dryness.

§ 94. **Details concerning the Bleach-out Process.**—Having explained the principle of the Bleach-out process, we will now consider it in detail.

Difficulties to be Overcome in Procuring Suitable Dyes.—It is extremely difficult to find dyes which possess all the requisite properties for producing a suitable bleaching-out paper. For example, (1) they must have no chemical effect on one another, and (2) they must bleach out equally. If one of them bleach out quicker than the other two, it is necessary to find some agent or compound which has to be added in order to retard

its action to the requisite degree. (3) After the colours have been bleached out by the light in the parts which represent the picture, those that remain must be capable of fixation so that the light will have no further action. (4) Since highly sensitive dyes cannot be permanently fixed, it has been found necessary to employ less sensitive dyes, in order to secure the essential property of stability on fixation. (5) These moderately sensitive dyes must be capable of being made temporarily highly sensitive, and then of being rendered less sensitive afterwards. (6) Lastly, the dyes must not only possess all these properties, but they must have the right shades or tones of Red, Yellow, and Blue, so that together they will produce Black, Greys, Browns, Greens, and Purples of the proper tones, so as to give correctly balanced mixtures. It will, therefore, be readily seen how extremely complicated the problem is, and what enormous difficulties have to be overcome, in order to produce ideal light-sensitive dyes.

Supposing that we have the right dyes, we have then to mix them and dissolve them equally and thoroughly in an emulsion of either gelatine or collodion. Such an emulsion must have no chemical or injurious action on the dyes, and should permanently retain a certain amount of moisture, because moisture favours oxidation, and therefore a bleaching-out action.

Now we may adopt one of two methods. We may either mix all three colours, red, yellow, and blue dyes with the gelatine or collodion, and then spread the mixture over the paper, as is done in the Uto-colour process; or we may coat the paper with three layers, each holding its respective dye, as is employed by

Szczepanik in his three-layer bleach-out paper. Each process has some advantages and some drawbacks. Both answer the purpose fairly satisfactorily, in fact, the single layer (Uto-color) process differs more in theory than in practice, because, so long as the emulsion is wet the colours gravitate, and thus arrange themselves into layers according to their solubility. Thus the red particles which are less soluble than the other two colours will be deposited first, then the yellow, and, lastly, the highly soluble blue. So that ultimately we get three layers just as in Szczepanik's process, the only difference being that the single layer resolves itself ultimately into three very thin layers, whereas the triple layer remains as a single thick layer. The Uto-color process has therefore the advantage of the three layers being closer together, and hence there is less parallax. Moreover, the Uto-color method can be produced much more cheaply, since there is only one layer to coat instead of three. On the other hand, with Szczepanik's method one may isolate each layer in turn and so prevent the three dyes from acting chemically on each other, this isolation allowing of a larger range of colours. Szczepanik has now overcome the difficulty of isolating and fixing the intermediate layer, which was at first a serious objection. He does this by spreading on first a layer of red stained gelatine, then a coating of varnish which has been stained yellow; and, lastly, a blue stained layer of gelatine.

In practice both methods will produce equally good prints. The Uto-color process is, however, the one most in favour at the present time.

Methods of Increasing the Sensitivity of the Dyes.—The dyes alone are not sufficient. It is necessary to increase their sensitivity to light. This is effected by means of either an ethereal oil such as Anethol, or Thiosiamine, which is a compound of Urea, discovered by Dr. Smith, the inventor of the Uto-color process. It is interesting to note that Urea itself, or one of its products, has been used by platemakers to increase the sensitivity of plates for many years past. Peroxide of Hydrogen has also been recommended, but as it rapidly decomposes into oxygen and water it is of no value. The special qualifications of a good sensitiser are that it should be permanent as far as its composition goes, it should be non-volatile, and easily removable. There is still a great demand for a good sensitiser, as all those which we know of possess certain drawbacks.

In selecting a support for the gelatine containing the three colours, the paper should be perfectly neutral and indifferent, *i.e.* it should possess no chemical properties which can act on the gelatine, and it must be protected by means of an insulating material from becoming stained by the dyes. When the Uto paper was first issued it was found to be stained pink by the acid red dye (Erythrosine) which leaked out of the gelatine. At the present time a basic red dye is used instead, being better adapted for several reasons.

§ 95. **The Nature of Dyes.**—Dyes are of three kinds, basic, acid, and neutral. Basic dyes are salts of the colour bases, which latter form the real colouring principle. It may be just as well to explain here the meaning of a few terms which are constantly used in

connection with this subject, viz. Bases, salts, acids, and colloids.

A Base is a substance which combines with an acid, and neutralises it to form a salt. It is usually an oxide, and sometimes a derivative of Ammonia, and when it combines with an acid, water is formed. Bases are nearly always alkaline, or if not, neutral, and have the opposite character to acids. Thus a Base usually turns red litmus paper blue, whereas an acid turns blue litmus paper red. When it unites with an acid the acid is neutralised, and a salt is formed. For example, Sodium Carbonate (Na_2CO_3) is a base. If Hydrochloric acid (HCl) be added to the base, a neutral salt (common salt, or $NaCl$) is formed, which is composed of the metal sodium and chlorine gas, while water and carbonic acid are liberated. A neutral body such as common salt is neither acid nor alkaline, and therefore has no effect on litmus paper.

A Salt, then, is a compound formed when the Hydrogen in an acid is partly, or entirely, exchanged for a metal.

An Acid is a substance containing Hydrogen which reddens litmus paper; and when it unites chemically with a base, the Hydrogen is replaced by the metal of the base (if one is present) and a salt is formed. Thus KHO and K_2O are bases. Sulphuric acid (H_2SO_4) is an acid. If one of the two comes in contact with the acid, either one or two atoms of Potash are capable of exchanging places with the Hydrogen to produce one or other of the salts, Potassium Sulphate (K_2SO_4) or Hydro-potassium Sulphate ($KHSO_4$).

A Colloid is a viscous or jelly-like substance, which

in solution will not pass through an animal membrane. Indiarubber, Gelatine, and Collodion are examples of colloids. They are very intractible and difficult to analyse. A colloid is necessary to hold the colour in solution in a printing-out paper.

Acid and Basic Colours.—These are nearly all Analines (Coal-tar products), and comprise the vast majority of dyes used in commerce to-day. The real colouring matter of such a dye lies in the colour base. If such base is combined with an acid it forms a basic dye which is merely a salt of a colour base. The most important dyes used in colour photography are the following:—

Reds.—Rhodamine, Saffranine.

Blues.—Methyl violet, Diamine blue, Methylene blue.

Yellows.—Chrysophenine, Auromine, Chrysoidine.

Acid Dyes.—These form by far the largest group of dyes. They are all salts of the colour acids. Just as in the former class a colour base or alkali forms the real colouring principle, so in this case an acid colour body does the same. When this acid is combined with a colourless base, *e.g.* Soda, Lime, or Ammonia compounds, we get an acid salt. And as in the former case the acid has no effect on the colour, so in this case the addition of the base neutralises the acid, and consequently does not change the colour.

Acid dyes are of course acid, and they dye substances best in an acid bath. The chief acid dyes used in colour photography are as follows:—

Reds.—Echt Rot, Glycinred, Krapplak, Biebrich scarlet, Erythrosine, Irisine, Isocyanine, Rose

Bengal, Eosine, Methyl red, Nitrate of Æthylred, Æthylred, Chinolin red.

Yellows.—Phenosaffranine, Rapid filter yellow (Hoechst), Naphthol yellow, Normal gelb, Pinachrome, Æsculine, Methyl orange, Aurantia, Picric acid, H. Naphthol orange, Eosine yellow.

Blues. — Cyanine, Fast blue, Methylene blue, Normal blue, Milori blue, Peacock blue.

Greens.—Fast Green, Acid green.

Mineral and Vegetable Colours.—These form a class by themselves, and are largely used for printing-inks in colour photography. Such are, for example :—Chrome yellow, Cadmium yellow, Zinc yellow, Prussian blue, Madder lake, and its artificial derivative Alizarin. They are all mordants (that is, self-fixing), and are very permanent.

All the dyes required in photography may be obtained from one or other of the following firms :—

1. Actien Ges. für Analinfabrikation,
   Hoechst factory, Frankfort-a-M.
2. Bayer Elberfeld, Germany.
3. Berger u. Wirth, Benthstrasse, Berlin, for Normal Blue and Normal Red.
4. Böhringer Mannheim (for Æthylred).

Grübler und Holborn, Chemiker, 63, Baierische Strasse, Leipsig, or their agent, Charles Baker, 244, High Holborn, London, W.C.

Kast in Ehinger (for inks), A. and E. Lumière, Lyons.

Dr. G. Mündie, Mik. Chem. Institut, Göttingen, Hanover.

§ 96. **Uto-color Paper.**—In the year 1906, Dr. J. H. Smith, of Zurich, produced a paper covered with

a gelatine layer impregnated with the three primary colours. He called it Uto paper, the name being taken from a range of mountains near Zurich. This paper was at first of a greyish-green colour, but later efforts produced a black paper, which, as we have already pointed out, is the correct and in fact the only possible colour which the paper can have to give the effect of dark shadows. Obviously Black cannot be formed by any conceivable bleaching action, and if any black is to appear at all in the finished picture, it must be supplied by the unaltered paper. This paper proved very disappointing and unsatisfactory owing to the irregular way in which the colours printed-out, and to the great want of sensitiveness of the colours to light. Besides, in order to sensitise it before printing it was necessary to add Peroxide of Hydrogen. Subsequently, Dr. Smith discovered that Anethol was not only a better sensitiser, but could be incorporated in the colour layer, thus rendering the process of after-sensitising unnecessary.

Uto Rapid Paper. This paper is now manfactured and sold by the Société Anonyme Uto-colour, Rue de la Pointe, La Garenne-Colombes, Paris. It was introduced in October, 1911, and perfected a year later, and is a great improvement over the old paper. It consists of a paper covered with the following layers:—

1. The white paper support.

2. A white Baryta layer, which gives the pure whites in the finished picture after the colour layers are entirely bleached-out. The reader must remember that in the print we are dealing with colour formation by subtraction (subtractive process, see

p. 68), whereas in the formation of the positive the colours are produced by addition (additive process or colour synthesis). In the paper print the whites are produced by more or less complete removal of all three colours in the gelatine layer. The object of the Baryta layer is to afford a purer white than the paper alone would give.

3. The colourless insulating layer. This layer is necessary to prevent the colours from soaking through and staining the Baryta layer and the paper beneath.

4. The Gelatine Emulsion Layer. This holds the mixed red, yellow, and blue dyes, which are adjusted to form as dense a black as possible, and give rise to the blacks and dark shadows in the finished picture. The black has a slightly greenish tinge, but this is hardly noticeable. The gelatine emulsion is coated by machinery, and holds the three dyes and the sensitisers Thiosinamine and Anethol, and other compounds. A little glycerine is added to prevent the layer from becoming too dry.

Under a suitable positive, the colours print out fairly evenly, and give quite a good effect.

According to the makers, the paper keeps well in its original wrapper for about a year, if it is kept in a cool dry place. Each sheet is packed with the sensitive surface protected by a piece of brown tissue paper. This, as the author has pointed out, is a mistake, as in hot climates the tissue paper will stick so firmly as to render it impossible to remove it. He has suggested to the company that the paper should either be packed in air-tight and light-tight grooved boxes, so that the black surface should not touch anything, or else the

sheets should be in contact with celluloid films which would not stick. If the sheets become too dry, the emulsion films become brittle and crack; if they are kept in a damp place, they stick to the positive, and print out too green.

§ 97. **Practical Details of Printing on Rapid Uto Paper.**

1. *Subjects for Printing.*—Any colour screen-plate will do, and any subjects may be copied, but to get the best results, the following points must be attended to :—

(*a*) The colour transparency or positive should possess strong and brilliant colours since the pictures always lose a good deal of the original brilliancy and appear flat. This is due to the fact that the paper pictures are seen by reflected light, and not by transmitted light as the originals are.

(*b*) The positives should not possess great contrasts of light and shade, because to obtain these the colours must be entirely bleached in some parts and remain unaffected in others, and that is a result which is very difficult to obtain, since the light parts print out too quickly compared with the dark parts, which we know is the case in ordinary black and white photography.

(*c*) The illumination must be evenly distributed over the entire plate. The best subjects for printing are, therefore, positives which have rich saturated colours, without possessing great contrasts of light and shade, *i.e.* subjects which are not too hard.

2. *Preparing the Subjects for Printing.*—The positive must first be coated with a special varnish supplied by the Uto-color Company, since the ordinary varnishes have too low a melting point. If the Author's alum

trough dish be used no varnish is required, since the alum trough absorbs all the heat. The plate must first be gently and evenly warmed (but not heated, or the film will be injured), and the plate is then held either between the fingers at the sides, or on a pneumatic rubber glass holder, and the varnish is then liberally poured over the middle of the plate, and by gently rocking the plate, is made to distribute itself up to the four corners alternately, and the remainder is then poured back into the bottle by tilting up the opposite end. A little practice will enable the beginner to pour it on evenly. The great point is not to have the varnish too concentrated, otherwise it becomes very difficult to apply evenly. The beginner should practise it on a spoilt negative a few times first, as he is apt to spoil the picture when he tries to dissolve it off in order to get rid of the lines and ridges. The plate should be gently warmed again after varnishing until it is no longer sticky, but has become quite dry.

3. *Printing the Picture.*—This is conducted exactly in the same way as with an ordinary printing-out paper. The paper is taken out of the packet in one's shadow at the end of the room away from the window, the black side of the paper being in contact with the film of the positive in the printing frame. The Author invariably fits a plate of clear glass inside the frame against which the glass side of the negative rests. This is advisable for many reasons, and is indispensable if the negative (or positive) is smaller than the frame. When all is adjusted, the frame is placed in the open air and, if possible, in direct sunshine, so as to reduce the time of printing.

The Author has already recommended the use of an alum trough. This consists of either an all-glass trough, or, what is better, a sheet of ordinary clear glass fixed with putty into the bottom of a wooden frame about 1½ ins. high. This is then filled half-way up with a 3 per cent. solution of common alum in tap water (that is, about 15 grains to the ounce of water). The trough should be a little larger than the frame so as to prevent any shadows being on the picture. The object of the alum trough is to absorb all the heat rays, which latter would otherwise tend to injure the positive and soften the gelatine layer of the paper Any scratches or marks or unevenness in the plate at the bottom of the trough will not affect the print, since the glass is too far away from it.

The time of exposure varies from an hour to three hours in the full sunlight in summer, according to the nature and density of the positive. In diffused day-light the time will, of course, be considerably increased. From time to time a corner of the print should be examined to see how the printing is going on.

Sometimes the prints will be found to stick to the positives. This always occurs if either the varnish or the black colour layer is not perfectly dry, but it may occur even if they are dry. This will happen if the gelatine layer of the paper or the varnish of the positive gets too hot during the printing in the sun. We can avoid this in several ways. We may largely prevent it by using the alum trough above mentioned. Or we may put one or two drops of olive oil on the centre of the black layer of the paper, and gently rub it evenly over the surface with the finger, or a smooth soft pad, being

careful not to put too much on so as to leave rings or lines of oil behind. These must be mopped up, or they will leave marks in the printing. Lastly, we may place a very thin layer of celluloid between the two surfaces, a piece of a Kodak roll-film carefully cleaned will do perfectly.

The Uto people claim that more than a hundred prints can be made from a single diapositive, but they do not say what effect such prolonged exposure to the sun's rays will have on the originals. For my part I would not risk more than two or three prints off it. Should a greater number be required, it would be much safer to take a copy by direct contact, or through the camera, and then print off the copy.

§ 98. **Methods of Improving the Print.**—It is found to be very difficult to keep the blacks pure, while at the same time bleaching out the high lights so as to get good pure whites. Worel, Miethe, and others suggest overcoming the difficulty by making a negative copy on an ordinary gelatine plate, and then taking a positive from that. This black and white positive is then substituted for the colour positive and a preliminary print is made on the Uto paper so as to bleach out the high lights. The colour positive can then be substituted for the black and white positive (being careful to secure exact register), and the colours printed out in the usual way.

Printing-filters of yellowish-green of different shades (marked G and MG, MG being twice as dense as G), can be had from the Uto-color firm. Either one of these may be placed over the positive so that all the light will filter through it. These filters are useful to

check unequal printing. Thus, if the blue and yellow dyes bleach out quicker than the red (which is usually the case) a green filter will allow most of the blue and yellow rays to pass through, and very few red rays. According to the bleach-out law, since the blue and yellow rays pass through the filter, they will to a great extent bleach out the opposing colour red, but will only slightly affect the other two colours. Hence by using the filter for a certain time, we can regulate the effect on the three colours, so as to get an even balance between them. In the same way, if the green colour tends to predominate we can adjust matters by using a light red filter. According to the Uto-color manufacturers, if the paper is slightly damp, greens will predominate, or in other words the blue and yellow colours will bleach out faster than the red.

§ 99. **Fixing the Uto-color Prints.**—The prints must now be fixed. This is effected, 1st, by removing the sensitive products resulting from the bleaching out of the dyes, and 2nd, by making the dyes stable to light. Unfortunately up to the present neither of these essentials can be perfectly fulfilled. Still the prints can be fixed quite sufficiently to render the colours permanent if kept in an album. If mounted and hung on the walls they must be placed where no direct light from the window can reach them. If the print has been oiled, the oil must first be removed with a soft pad soaked in benzine. Then the picture is placed for half an hour in a bath containing 35 grams of Tannin to 100 c.c. of methylated spirits (15 grains to the ounce). About $3\frac{1}{2}$ ounces will suffice for 4 quarter-plate prints. The tannin solution dissolves out the sensitisers and

bleaching products, and in addition hardens the film. Next wash the print for three minutes under the tap, and then place it in the fixing bath. This bath consists of a liquid sold by the Uto-color Co. in a concentrated form. It is a green strongly smelling liquid. One ounce of this is to be diluted with 3 ozs. of water. The prints should be left in for about three minutes. They are then rinsed for about a minute under the tap, and dried as quickly as possible. This is best done by squeegeeing the print film downwards on to a sheet of glass, or japanned iron if a glossy surface be desired, or ground glass for a matt one. The back of the print is then dried with blotting paper, and the print left to dry. The glass on which the print is squeegeed must first be thoroughly cleansed, and then wiped over with French chalk, or a little wax dissolved in benzole in order to prevent the film sticking.

§ 100. **Uto-color Stripping-paper.**—When a photograph is taken on an ordinary plate the picture is reversed, *i.e.* the right side of the object appears on the left, and the left on the right side of the negative, but when the print is made the position is reversed again, so that the print corresponds to the object. If a colour positive is taken, the position of the object is correct, because the plate is put into the camera with the glass side, and *not* the film side towards the lens; and so when a print is made, whether coloured or plain, the position is reversed. The picture will only correspond to the original when it is held up to the light and looked at from behind.

One may obtain a correctly placed picture in three ways.

1st. We may use a reversing prism when taking the positive, and the print made from this will be correct. But reversing prisms are very expensive, and few amateurs possess one.

2nd. We may employ a colour-film fixed on a very thin celluloid sheet, and print through the back. Such films can be had from the Neue Photographische Gesellschaft (New Photographic Company), Steglitz, Berlin.

3rd. We may use a bleach-out paper which can be stripped like carbon tissue. This is now supplied by the Uto-color Co., and is likely to supersede the ordinary rapid Uto-color paper.

The stripping-paper is used exactly in the same way as the Uto paper just described. It may be oiled just before printing. Then the film is lifted up at one corner with a penknife, and stripped off with the fingers. It is then carefully laid on the film side of the positive, and a piece of black paper is laid on the top of it. The cover of the frame is placed on it and fastened down, and the positive exposed to the light.

In order to watch the progress of the printing, one half of the frame-cover is lifted up, and a sheet of white paper is inserted a little way between the positive and the film, since it is impossible to see the picture on a black support.

After printing, the film is placed on a glass plate and the oil removed with a pad soaked in benzine. It is then laid face upwards on a piece of stout Baryta paper which should be slightly larger than the film. A sheet of paper or cardboard is now selected on which to mount the film, and the latter with its Baryta

support is squeegeed face downwards on to the mount. As soon as the gelatine has set, the Baryta support is pulled off, leaving the film (now right side up) on the paper or cardboard mount. It is then left to dry in a dark place.

§ 101. **Uto Lantern Slides.**—The stripped Uto-color film may be printed and mounted on a glass plate instead of on paper, and thus can be used as a grainless lantern slide. The glass plate must be dipped into a 3 per cent. solution of gelatine, just as was done in the case of the mount, and the film squeegeed on, while the gelatine is hot. It is recommended to cover the film with a thin sheet of rubber to prevent the film being damaged while it is being squeegeed. The glass transparency is then allowed to dry in a dark place, and afterwards fixed in the usual way, except that a 3 per cent. solution of Chrome Alum is to be preferred to the tannin bath. A cover glass is finally added and bound round with binding strips, or, what is much better, with a long strip of adhesive surgical plaster $\frac{7}{16}$ths of an inch (11 mm.) in diameter. Uto lantern slides possess much more brilliancy than Uto papers since they are seen by transmitted light, and moreover they do not require to be printed quite so deeply. Whether their colours will stand the prolonged action of the luminant remains to be proved.

CHAPTER XII

KINEMATOGRAPHY BY MEANS OF COLOURED LIGHTS

§ 102. **Projection of Kinematograph Pictures in Colour.**—The extraordinary popularity of screen pictures of moving objects has led to innumerable attempts to still further the illusion by representing the scenes in colour. This has been frequently done by staining the film, and in this way effects in which browns or greens are predominant, or moonlight scenes, can be obtained; but although such effects are pleasing at first, the eye soon gets tired of the unreality. Colouring the films by hand is possible, but tedious beyond measure. When one considers that many films measure 1000 feet and contain over 16,000 separate pictures, the time and expense required to colour such a film are very great. In spite of the difficulties, hand-coloured films are still produced to a considerable extent. The colours are never brilliant and as far as I can ascertain are limited to pink, bluish-green, yellow and brown. Notwithstanding this the films are quite a success, and in the writer's opinion are far more pleasing and agreeable to the eye than the kinemacolor films.

§ 103. **The Urban-Smith "Kinemacolor" Process.**—Mr. Charles Urban and his collaborator, Mr. G. Albert Smith, after a prolonged series of experiments,

have at length succeeded in exhibiting kinematograph pictures in colour, which for brilliance of colour effect are unequalled by any other method. Although only two colour-filters are used in projection, a red and a green, these brilliant colours and their orange and yellow combinations, as well as browns, greys, *eau-de-nil*, and even blues and indigoes, are in evidence. The green filter used is one which transmits a considerable amount of blue light, and therefore the resultant picture gives not only the effect of blue sky and water, but a very considerable range of combination of all the colours, as well as white and black.

The principle of the Kinematograph depends on what is called "persistence of vision" and the continued perception of the changing object. When light is reflected from a moving object it forms an image at the back of the eye, and produces a nerve current which passes along every one of the fibres which receive the image and collectively carry the impression along the optic nerve to the brain. This sensation is not instantaneous, but is divided up into four periods: 1st, a latent period which is almost instantaneous, and during which nothing appears to happen; 2nd, a very short period—probably less than $\frac{1}{100}$ of a second —during which the sensation reaches the maximum; 3rd, a much longer period, $\frac{1}{30}$ to $\frac{1}{10}$ of a second (the time varying directly with the intensity of the illumination), during which the sensation slowly diminishes; and 4th, a short period of decline, during which the effect dies away. In the case of a moving object on which attention is directed, the fourth period remains unnoticed, because a new image

takes the place of the old one before that period arrives. The whole of kinematography depends on this third period, by which the first impression, A (Fig. 26), lingers until replaced by the second one, B, and the second one is again replaced by a third one, C, and so on.

We have suggested this in the diagram, in which the height of the curve represents the intensity of the light stimulus, and the width or base the time.

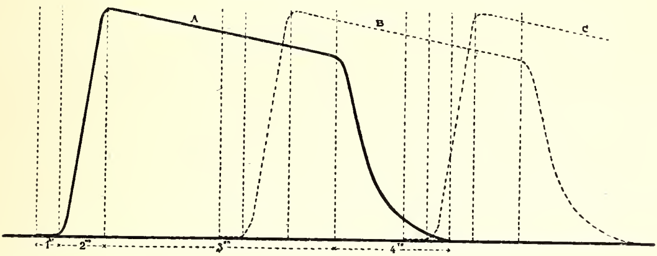


Fig. 26.—Curve representing the four periods of a visual sensation. The first sensation is represented by a thick line, the two succeeding ones by dotted lines. 1. Short latent period; 2. Period of increase to maximum; 3. Long period of persistence of sensation with gradual decline; 4. Period of rapid fall and obliteration of the sensation. In reality the sensations overlap very much more than here shown, but they are separated in the diagram for the sake of clearness.

This explains why, when a lighted stick is whirled round, it forms an unbroken circle of fire, and why a stream of water allowed to drop from a pipe appears to form a continual stream, and not a series of droplets, as is really the case; and just as the first impression of a moving object melts into the next one, so a series of colours pass before the eye, as in the familiar colour-top

which carries a card divided into sections painted blue, green, and red. If the top be spun rapidly, each colour fuses into the next, and a combined sensation of white appears to the eye. It is this last principle that Mr. Urban and Mr. Smith have so cleverly made use of in their "Kinemacolor" apparatus.

In working out his method of kinematograph pictures in colours, Mr. Smith based his first experiments on an instrument somewhat similar to the Ives' Kromskop, and also on the same inventor's triple projecting lantern. The principle of the analysis of the colours in the object photographed, and the subsequent building up of the colour-records to produce a coloured result, are similar in both cases. In his earliest experiments, he made use of strip-film negatives taken alternately through red, green, and blue filters. When he had made a positive film from this negative film, and proceeded to project his pictures on to the screen by red, green, and blue light respectively, the results were almost colourless, on account of the excessive actinic action of the blue light which had produced the blue negative record; and the correspondingly overpowering effect of the blue light which reached the screen through the blue filter. This obliterated both the other two images. In other words, the exposure necessary to get satisfactory red and green records was utterly out of scale with that required for the blue record.

Another serious objection to the use of red, green, and blue was that the normal speed of the kinematograph film, which is one foot per second (each foot carrying sixteen exposures), required to be increased

to three feet per second (forty-eight exposures in the same time). Such an increase of speed would, of course, involve prohibitive expense and complicated and expensive mechanical devices for the manipulation of the films at this high speed.

Further experiments with the Ives' Kromskop and the comparison of the appearance of the coloured image when viewed in daylight (illuminated with white sky) as compared with artificial illumination, led Mr. Smith to the following discovery. If the blue light in the former case were cut off, the appearance of the coloured image was utterly spoilt. In the latter case, however, the blue light could be dispensed with altogether without seriously altering the effect of the coloured image. He attributes these phenomena to the fact that most artificial lights are very deficient in blue—a fact well known to every photographer. Our eyes are to some extent accustomed to this excess of red and green rays (*i.e.* yellow rays) and deficiency of blue ones.

As a result of the above, Mr. Smith has perfected the "Kinemacolor" apparatus to use red and green filters only, the want of blue being met by using a green filter which passes a considerable amount of blue light.

Herr Kasimir Proszynski in a Paper read before the Royal Photographic Society (see *Journal R.P. Society* for March, 1913) considers that the continuity of kinematograph vision is a purely psychological illusion, and is not dependent on the persistence of vision hitherto believed to be the cause. He employs a shutter consisting of three similar wings separated by three intervals of precisely the same shape, for

according to him three wings are necessary. By revolving this shutter 15 times a second, we obtain 45 alternations of light and dark, and 15 separate pictures, which is just sufficient to eliminate all flickering. He states that intervals of $\frac{1}{40}$th to $\frac{1}{50}$th of a second comprise the limit of our perception, and that this interval is necessary to avoid flickering. Although the writer has studied Herr Proszynski's paper carefully, he cannot see anything in it which refutes the usually accepted theory, nor does he see wherein his modification of the shutter is superior to the ordinary form in use.

§ 104. The **"Kinemacolor" Camera** is similar to that used in ordinary black and white kinematography, except that it is built to run at twice the speed, viz. two feet, or thirty-two exposures, per second. The shutter used is, of course, a rotary one, and so geared to the handle by which the film is moved that the light only reaches the film whilst it is at rest. The essential difference between the ordinary kinematograph camera and the "Kinemacolor" camera is that the latter has a rotating colour-filter which is placed between the lens and the shutter. This filter consists of an aluminium skeleton wheel having one segment filled in with red-dyed gelatine, and a similar one filled in with green-dyed gelatine, and is so geared that the exposures are made through the red gelatine and the green gelatine filters alternately. The film, when thus exposed, is developed and from it a positive film is made by contact in the ordinary way.

If the negative "Kinemacolor" film be examined it will be found to consist of images in pairs, which

PLATE XI.

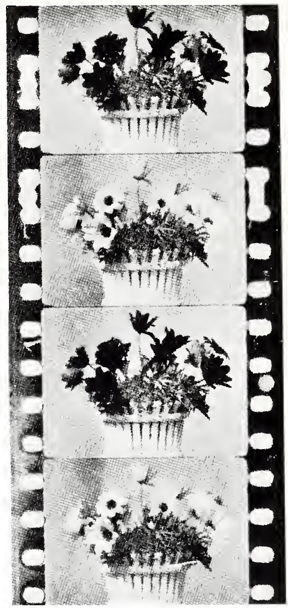
Through
green filter.

Through
red filter.

Through
green filter.

Through
red filter.

Kinemacolor negative film.



Kinemacolor positive film.

To face p. 208.

differ from each other inasmuch as they are records of the red and the green in the object photographed.

We have selected for our illustration (Plate XI.) four successive pictures of a plant, with bright red flowers and green leaves, standing in a brown flower-pot. The first exposure is made through the green filter. As nearly the whole of the red and much of the blue are absorbed by the filter, the red flowers in the negative will show hardly any silver deposit, while the green leaves will be quite dark, and the brown flower-pot will have an intermediate hue. On making a positive, everything will be reversed. The red flowers will show a dense deposit, the green leaves hardly any, and the brown flower-pot an intermediate one.

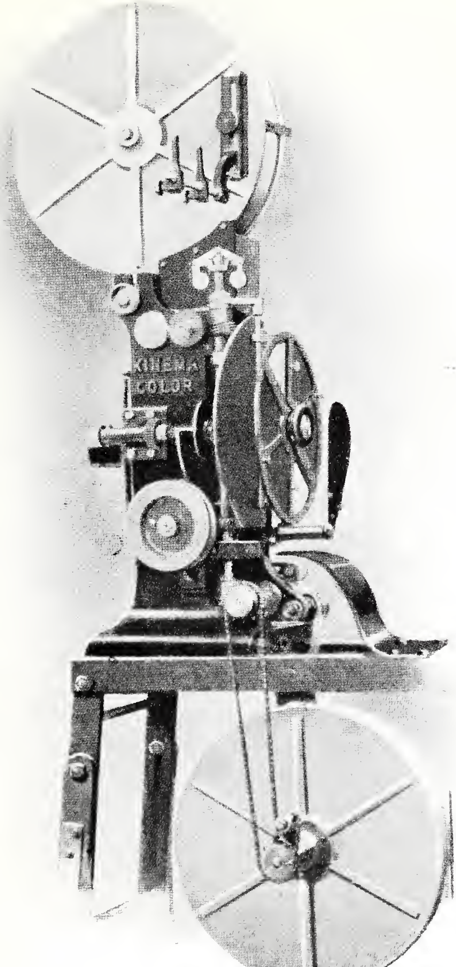
The next exposure, taken through the red filter, will exhibit exactly the reverse. If you look at the positive (Plate XI.) you will notice the red flowers show hardly any deposit, and the leaves are quite dark, while the brown pot, since it is merely a mixture of red, green and a trace of blue (all degraded with black), has the same density in both positives.

§ 105. In the "**Kinemacolor" Projector** the rotating colour-filter is placed between the condenser and the gate or fire-proof shield. When the two pictures are rapidly projected one after the other on to the screen the combined effect gives rise to red flowers and green leaves in a brown flower-pot—as it should be. Had the positive film been placed in the wrong order, *i.e.* the "green" picture opposite the red light, the colours would have been the complementary ones, all through the film. So in order to prevent mistakes, a white dot is placed on the film opposite the "green" picture

in the black and white image which has to be projected by green light. If on rotating the handle the colours are seen to be complementary, it may be instantly remedied by shifting the mask one whole picture width either up or down, and at the same time recentring the arc or limelight. Furthermore, whenever a title appears on the film, it should be so threaded as to show red letters on the screen. If this is done all the colours will come in their right order. It will thus be seen that with a little care both the taking and exhibiting of "Kinemacolor" pictures are very little more difficult or troublesome than ordinary black and white pictures, while there can be no doubt that with films correctly exposed and developed and in perfect register, the pictures in colour are often more pleasing to the eye than the ordinary black and white.

The chief defects of kinemacolor pictures are: 1st. If the objects move rapidly, fringes of red and green are seen bordering the objects. Thus, if a person suddenly raises his bared arm, it will appear at one moment red, at another moment pink, and again greenish; or else the arm will have a fringe of red or green. 2nd. The range of tints and hues is very limited. This is inevitable, seeing that all the effects are produced by means of the rotation of two colours—an intense red, and an intense green disc. 3rd. The colours are painfully intense and vivid. There is an entire absence of greys and neutral tints, which are always present in nature, and which soften and tone down the harsh and saturated colours. But considering the limitations, the results reflect great credit on the inventors.

PLATE XII.



The Kinemacolor Projector, showing Colour Filter in position.

To face p. 210.

In preparing the rotary colour-filter it is necessary to bear in mind that red is more vivid to the eye than green, so that the balance of colour in the two dyed gelatines must be correctly maintained. This is done by making the red the standard, and adjusting the green to equalise it.

A single film of red gelatine and one of green being fitted to the shutter, a second film of green gelatine is added to the first, trimmed to the requisite width, by trial, and then affixed to it. As a rule it is made to occupy the middle third of the gelatine. If it is too narrow the green will preponderate and yellows will have a greenish hue; if it is too wide the green will be too dense and the red will be in excess, so that yellows will have an orange hue. If of correct width the filter on being rotated will show a disc on the screen of a neutral white hue.

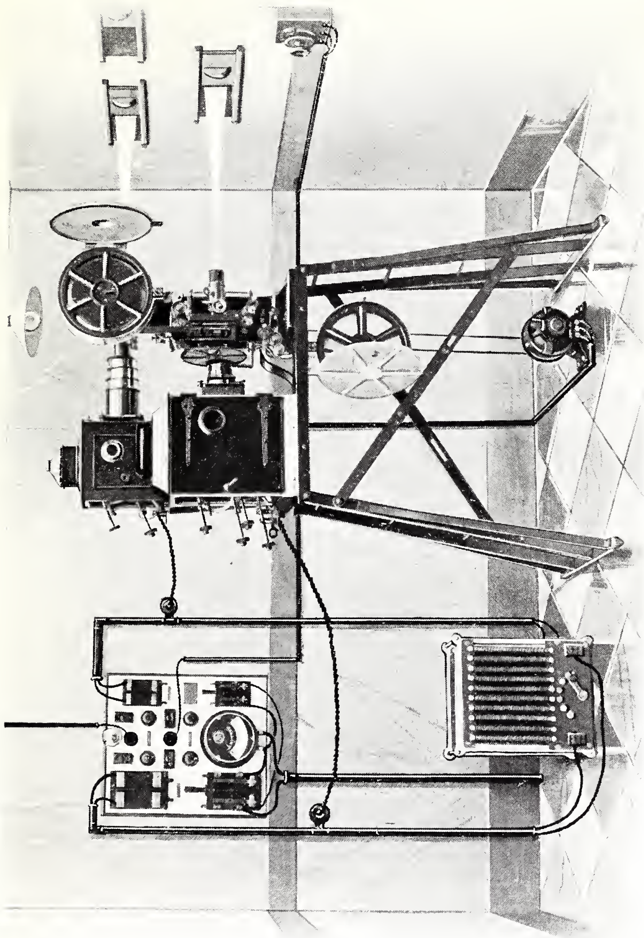
The perfection of the picture on the screen is largely due to the correctness of the exposure and the skill of the photographer. If more than two feet of film were exposed per second the objects would appear to move slowly; if less, too fast. If the exposure is too short the colours will be unnaturally vivid, if too long the colours will be dull. On the other hand, if the subject is too brightly lighted the picture will be white or colourless. If too dark the colours will be poor, clogged, and without detail.

It might rightly be asked, if only red and green filters are used, how can blue effects be produced? One may either use a yellow-green filter which would give the correct hue to grass and foliage, or a deep blue-green which would give an imperfect colour

to grass, but which in artificial light would give an effect indistinguishable from a pure blue itself. Hence, Mr. Smith has made a compromise by sacrificing a little of the purity of each. If the green used for projection (which, by the way, is a different shade from that used for exposing the film) be examined by the spectroscope, it will be noticed that quite a considerable amount of blue passes through in addition to the green. In the next place advantage has been taken of the effect of yellow light on greens. Now, if blue be mixed with a very large proportion of white light such as we find in our Northern blue skies, or reflected from large sheets of water, and it be seen through a green glass—although it appear greenish in daylight—yet in artificial light it will appear indistinguishable from blue, and that is what happens when projected on the screen. The blues of the sky and sea or rivers appear to the eye on the screen as greenish-blues, although taken through a green filter, and the effect is sometimes natural and pleasing. Furthermore the combination of the red and green lights gives rise to the sensation of greenish-yellow, pure yellow, or orange, according to the preponderance of green or red light in this mixture. In any case there is always a trace of residual yellow and residual blue in the high lights. Hence, the addition of this residual blue to the yellow will give rise to white. This is the explanation of how the whites and the blues are reproduced by "Kinemacolor."

§ 105A. **Gaumont's Method of Colour Cinematography.**—Although this method is the oldest of all, it is in the writer's opinion superior to the Kinemacolor

PLATE XIII.



Apparatus arranged for Kinemacolor Projection.

To face p. 212.

process, and is briefly as follows. Three small cinematograph pictures are taken with an exposure of the 1/30th second through three lenses simultaneously, each being furnished with its respective colour filter, and after each exposure the film is moved on over the space occupied by the three pictures, *i.e.* about 56 mm., or roughly two and a quarter times as much as for the ordinary cinematograph picture. Projection is accomplished by three lenses, each carrying its own colour filter, which is slightly different from the one used in taking the negative, and registration is effected by moving the top and bottom lenses in three directions by a very ingenious mechanism. This method only reached a practical stage by the production of exceedingly rapid and highly colour-sensitive emulsions.

CHAPTER XIII

COLOUR PHOTOMICROGRAPHY

§ 106. Permanent records of microscopic objects are so essential that no worker can afford to be without a photographic camera, since the old methods of drawing objects through a camera lucida can never be absolutely reliable, and are besides tedious to execute. Objects which require a high magnification to be seen, are nearly always transparent, and can be made out just as well in monochrome, provided that a panchromatic (or Wratten M plate) with a suitable colour filter be used. Still, since many anatomical and botanical structures take on a selective action with certain stains, it is advantageous to reproduce them in the colours seen. Moreover, when slides are projected on to a screen, the effect is greatly enhanced by colour, and often details can be shown which are lost in monochrome.

The five methods at present in use are the Autochrome, the Dufay, the Paget screen plates, and the three and two separate plate methods.

As regards the choice of methods, the three and two colour separate printing methods are undoubtedly the most satisfactory, but at the same time the most tedious, and present far more technical difficulties to

the amateur except in practised hands. They are entirely free from all traces of grain, and thus show up the finest detail, and by reason of their great transparency form ideal slides for the lantern. Nevertheless, the single-plate methods are so simple that most workers will use nothing else. The Dufay and Paget plates are much the best for lantern projection, but the Autochrome plate is preferred by many, because the colours are truer to nature, and the losses through failures are fewer than by any other method. Since the working details of all these processes are given very fully in other parts of the book, they need not be referred to here.

It is in opaque objects that colour is best shown, and such objects rarely require high magnification, *i.e.* above 30 or 50 diameters. Low power microphotography presents far fewer difficulties to the tyro than high power work, since none of the adjustments require anything like the same precision in regulating, in fact, below 50 diameters a substage condenser will rarely be needed.

We may divide the subject into two heads: low power, and high power photomicrography.

§ 107. **Low power Photomicrography.**—A few points may be useful to the reader regarding the apparatus.

The two most essential things are: first, to secure rigidity and freedom from all vibration in all the parts; and secondly, correct centering of the axial rays.

The table.—A strong kitchen table answers every purpose. A couple of rails or guiding rods, made of mahogany, and extending the whole length of the table

on either side of the middle line, and about five inches apart, should be screwed down.

The camera.—Each end of the camera should consist of a square frame of mahogany. The front part should rest below on a broad wooden or metal support, which fits exactly between the guides so as to allow of its sliding freely backwards and forwards without any side shake. The sides of the guides facing each other should have a rectangular groove (or rabbet) running the whole length, and each wooden support should be provided with a corresponding tongue which should fit the rabbet. This allows the supports to be clamped in any position along the table by means of a good broad screw, which screws through the support and can be made to press with its flat end against the table, the counter pressure being made by the tongue against the rabbet. Both the front and back of the camera, as well as the microscope, water-trough, screen, condenser, and radiant, should each be provided with a similar support, but as the camera front and back are the only parts liable to shift (owing to the spring of the bellows), the other accessories do not require a clamp. The camera should have at least $1\frac{1}{2}$ inches of rising front which can likewise be clamped in any position, while the back which holds the focussing screen and double slide should be fitted so as to allow its being moved laterally across the support through a distance of about $2\frac{1}{2}$ inches on either side of the middle line, and clamped in any position. The use of this will be explained presently. The ocular end of the microscope should be connected with the central aperture in the front of the camera (just inside the flange of the lens)

by means of a large metal collar which while excluding all extraneous light allows of free movement between the microscope and camera without the slightest contact between them.

The back of the camera must be square so as to allow of vertical or horizontal pictures being taken at pleasure. My camera is a whole-plate one, with adapters for half-plate, 5×4 and quarter plate sizes. This is the apparatus which I have used continually for many years past, and I have never been able to improve upon it. It was originally made from the description given in Dr. E. C. Bousfield's book,[1] which teems with original and valuable information.

The sliding support for the microscope should have a recess to hold each leg in position, or if the microscope has the German tuning-fork shaped foot, each prong can be clamped by a movable wooden button.

My camera has an extension of 4 ft. 4 ins., which just permits of 50 magnifications with a 25 mm. (1 in.) Protar Anastigmat screwed on to the front.

Any ordinary anastigmat of one, two, or three inches focal length will give just as good an image as the best microscope objective. Zeiss introduced a series of Planar objectives of 25 mm. and 50 mm. focal lengths, and F/4, 5 aperture, which are identical in construction with ordinary photographic objectives, and can be employed equally well for the microscope, bioscope, or snapshot camera. They are fitted with an iris diaphragm, and have the standard microscope screw. When screwed on to the front of the camera

[1] "Photo-micrography," by Dr. E. C. Bousfield. J. & A. Churchill, London.

enlargements may be photographed without a microscope or any other accessory apparatus.

§ 108. **Illumination.**—A bright, even illumination over the entire object to be photographed is of the highest importance. As a rule daylight can be employed with advantage, but in many cases, especially where high relief or shadows are necessary, artificial light is imperative. The simplest method is to place an incandescent bulb mounted on a stand on each side of the lens. It is well to fix a mirror or tin reflector behind the luminant, so that the light is concentrated on the object, and at the same time screened from the lens. By using only one light, or by placing the pair at different angles and distances from the object, the latter can be thrown into any required degree of relief or shadow. If two 60 c.p. Osmium incandescent bulbs be used, the exposure will be very short for unit magnification. I find 3 or 4 minutes ample when using a Planar lens, working at F/8. In order to ascertain whether the condenser is correctly centred, move the back of the camera with the screen fitted in its place, until the margin of the circle of light projected by the lens is brought into view. Then adjust the condenser or the radiant, until the margin of the circle is as sharp and free from colour as possible. If a projecting eyepiece is used, this same method will inform you at once which is the best distance of separation between the front and back elements of the ocular. Having made the necessary corrections, the back of the camera is swung round to its original axial position.

§ 109. **Methods of ascertaining the Magnifica-**

tion.—It is well to remember that whatever the focal length of the lens, the camera must be extended as many focal lengths $+ 1$ from the lens as the number of magnifications (m) required, while the distance of the object from the lens will always be the 1/mth of that distance $+ 1$. For example, suppose a magnification of 8 times (diameters) be required, and the lens chosen is of 3-in. focus. Then the camera must be extended $(8 + 1) \times 3$, or 27 inches from the optical centre of the lens, while the object must be 27/8 inches from the centre of the lens $= 3\frac{3}{8}$ inches. Again, suppose the object is to be taken natural size with the same lens. Then as the magnification $= 1$, the camera must be extended $1 + 1$ times F, or 6 inches, while the object will be 1/mth of that distance, or $1 + 1/1$ times $= 6$ in., *i.e.* the same distance as before. Lastly, suppose the object is to be reduced to $\frac{1}{8}$ the size, then the distances will be the same as in the first example, only image and object will have to change places, so that the object will now have to be 27 inches away, and the image $3\frac{3}{8}$ inches.

If we require the total magnification of the camera extension, plus the magnification produced by the microscope, we have to consider three factors.

First, we have the initial magnification produced by the objective. This is given in all the catalogues issued by the makers. It may be easily reckoned by adding a nought to the denominator of the focal length expressed in inches or fractions of an inch, and dividing this by the numerator. Thus, in the case of a 2-inch objective, the denominator being 1, we have for the initial magnification 10 divided by $2 = 5$ times.

In the same way a 1-inch objective magnifies 10 times, a $\frac{1}{4}$-inch objective magnifies 40 times, a $\frac{1}{12}$-inch objective 120 times, and so on. This initial magnification is again magnified by the eyepiece, which as we have shown is modified by the tube length as measured from the collar where the objective screws in, to the top of the tube, or a little below it. In most of the Continental makes this is 160 mm., while most of the English models measure 10 inches, or 250 mm. As a rule, the magnification is marked on the ocular for the tube for which it is to be used, but if it is to be used for any other tube length the factor is

$$\frac{\text{Actual tube length}}{\text{Standard tube length}} \text{ or } \frac{\Delta}{\text{Focal length of eyepiece}}$$

Δ being the standard tube-length. Thus, if the focal length of the eyepiece be 1 inch, or 25 mm., we shall have a magnification of 160/25 or $6\frac{2}{5}$ times for an average Continental microscope, or 250/25 or 10 times when used with an English standard microscope. Lastly, in order to get the total magnification of a compound microscope attached to a camera, it is necessary to multiply all three factors together. Thus, suppose we are using a $\frac{1}{12}$ inch objective with an inch ocular on a 10-inch tube, and the camera is extended 20 inches. The factor for the camera extension $= \frac{\text{extension in inches}}{\text{10 inches}} \text{ or } \frac{\text{extension in mm.}}{\text{250 mm.}}$, which in the above case $= \frac{20}{10} = 2$ times. Hence the total magnification $= 120 \times 10 \times 2 = 2400$ times. In order to check this it is quite easy to measure the magnification

direct. We place a microscope slide ruled in 1/10ths and 1/100ths of a mm. (which can be obtained of any dealer) on the microscope stage, and focus for one of the 1/10th divisions if for a low power, or a 1/100th mm. if a high power. Suppose in the latter case the interval between two lines measures 6·5 mm. on the focussing screen of the camera, then the magnification is clearly $100 \times 6{\cdot}5$ or 650 times.

§ 110. **Exposure.**—The correct exposure is, as we have more than once pointed out, of supreme importance. Many elaborate calculations have been given in the text-books for arriving at the correct exposure by multiplying various factors together, but the simplest and, as a rule, the best and most accurate way, is to make a series of trial exposures on a portion of the plates to be used. It is well worth while to have a special carrier made to fit into the slide. A quarter-plate can readily be cut up lengthways in a subdued Virida or Wratten "Safe-light" into three or four equal strips, and one of them placed in the carrier after the object has been focussed on the ground-glass. The shutter of the slide should have previously been ruled on the inside with white vertical lines, say 2 cm. apart, and numbered consecutively. When the slide is in position draw out the entire shutter, and expose for what you would consider to be about a quarter the correct exposure (say two seconds). At the end of the two seconds cap the lens, close the slide 2 cm., and expose the rest of the plate for another 2 seconds. Repeat the process and expose for 4 seconds, again for 4 seconds, and finally for 8 seconds. In this way the first two centimetres will have had 2 seconds exposure,

the next two centimetres 4 seconds, the third 8 seconds, the fourth 12 seconds, and the last piece 20 seconds respectively. When the strip of plate is developed, one of the portions will almost certainly be correctly exposed. This will be shown by giving a clear plucky negative, with full details in the half-tones and shadows, which latter should not be too dense to print easily, and a little experience will at once decide this when it is held up to the light. Once the correct exposure is known, any modification in the factors which influence it can at once be arrived at by calculation.

§ 111. **Factors which Influence Exposure.**—The following are the chief factors which influence exposure :

1. Character of the light.
2. Degree of magnification.
3. Numerical Aperture (N. A.).
4. Speed and colour sensitivity of plate.
5. Colour and density of screen.

1. *Character of the light.*—The following table gives the approximate factors for the most appropriate luminants :—

Light source.	Approximate candle-power.	Factor for		
		Panchromatic "M" plate.	Ortho-chromatic plate.	Ordinary rapid plate.
Oil flat-wick lamp .	15	1	4	8
Incandescent gas .	35–60	$\frac{1}{3}$	$\frac{3}{4}$	$\frac{4}{3}$
Nernst lamp (1 amp.)	200	$\frac{1}{12}$	$\frac{1}{5}$	$\frac{1}{3}$
Acetylene	40	$\frac{1}{12}$	$\frac{1}{6}$	$\frac{1}{4}$
Direct arc (4 amp.) .	300	$\frac{1}{50}$	$\frac{1}{33}$	$\frac{1}{33}$
Direct arc (30 amp.)	3000	$\frac{1}{1000}$	$\frac{1}{700}$	$\frac{1}{700}$

Theoretically the exposure is directly proportionate to the candlepower. As, however, different kinds of luminants vary enormously in their richness in blue-violet rays, as well as in the amount of yellow light, it is impossible to calculate off-hand what the exposure should be with any other kind of luminant. The above table based on practical experience will be found very useful. They are for the most part taken from the "Kodak" pamphlet, "Photomicrography," issued by the Kodak Co., Ltd.

2. *Effect of magnification.*—The exposure varies as the square of the magnification. The following table is based on this law:—

Magnification.	Exposure.
10	$\frac{1}{100}$
25	$\frac{1}{16}$
50	$\frac{1}{4}$
100	1
250	6
500	25
1000	100

3. *Effect of N. A.*—The exposure varies inversely as the numerical aperture.

Objective.	Average N.A.	Exposure.
2″ or 50 mm. . .	0·15	. . 10
1″ or 25 mm. . .	0·25	. . 4
$\frac{2}{3}$″ or 16 mm. . .	0·35	. . 2
$\frac{1}{2}$″ or 12 mm. . .	0·45	. . $1\frac{1}{4}$
$\frac{1}{3}$″ or 8 mm. . .	0·50	. . 1
$\frac{1}{4}$″ or 6 mm. . .	0·8	. . $\frac{2}{5}$
$\frac{1}{6}$″ or 4 mm. . .	0·85	. . $\frac{1}{3}$
$\frac{1}{8}$″ or 3 mm. . .	0·9	. . $\frac{1}{3}$
	$\frac{1}{3}$ to $\frac{1}{4}$ apoch. oil imm.	. . $\frac{1}{4}$ to $\frac{1}{8}$ or $\frac{1}{9}$
$\frac{1}{12}$″ or 2 mm. . .	$\frac{1}{3}$ to $\frac{1}{4}$ imm.	. . do. do.

4. *Speed and colour sensitivity of plate.*—These factors are generally given on the boxes and indicated by H. and D., Watkins, or Wynne. (See Appendix.)

5. *Effect of colour and density of screen.*—This varies considerably with different kinds of luminants.

EXPOSURE FACTOR OF WRATTEN'S "M" PLATES WITH VARIOUS SCREENS AND LUMINANTS.

Screen.	Transmission.	Oil.	Nernst.	Arc.	Incand. Gas.	Acetylene.
A Scarlet . . .	red end to line 590$\mu\mu$	3	6	6	6	5
B Green	600–460$\mu\mu$	12	12	12	12	12
C Blue-violet . .	510–400	25	16	12	12	12
E Orange . . .	red end to 560	2	3	6	6	4
F pure Red . . .	,, ,, 610	6	6	8	12	8
G strong Yellow .	,, ,, 510	$1\frac{1}{2}$	2	4	4	3
H Blue	540–420	24	16	12	16	16
K_3 for orthochro. production . .	—	$1\frac{1}{2}$	$1\frac{1}{2}$	$1\frac{1}{2}$	3	2
A and D deep Red	red end to 640	60	90	240	240	120
B and E Yellow-green	560-600	120	60	250	120	90
G and H pure Green	510-540	1000	1600	1600	1600	1600
B and C Blue-green	460-510	1000	600	600	1000	800
D and H Violet .	420–460	200	150	64	160	90
B and G Green .	510-600	25	25	64	20	30

According to Messrs. Hind and Randles, liquid screens of the same light transmission have, as a rule, lower factors.

The way to make use of these tables is as follows: If, after having made a trial experiment in the way previously indicated by giving a series of different exposures, you merely require to alter one of the factors, say, the magnification, it resolves itself into a simple rule-of-three sum to obtain the correct exposure. Thus, suppose your first magnification was twenty-five times, and you require a second negative with a magnification of 100 diameters, then, if the correct exposure was 3 seconds, with an oil lamp having a factor of 1, with the new magnification and employing incandescent gas having a factor of $\frac{1}{3}$, the correct exposure will be $3 \times \left(\frac{100}{25}\right)^2 \times \frac{1}{3}$, or 16 seconds. Of course, all the other factors must be dealt with in the same way.

§ 112. **High-power Photomicrography.**—It is assumed that the reader is acquainted with the general principles of high-power objectives and substage illumination, and they will, therefore, not be further discussed. The microscope, camera, and condenser system may be arranged either in the horizontal position or vertically, in which case the light is thrown vertically upwards along the optic axis by the ordinary substage mirror.

The advantages of the horizontal form are that one can sit comfortably while arranging the specimen under the microscope, and when focussing on the screen. Further, that a very great extension of camera may be employed.

The objections are that fresh liquid preparations

are inadmissible, and that the viscosity of the cedar oil often interferes with the final focussing when using immersion lenses, by rendering it necessary for the slide to be held down by clips, which are absent in most mechanical stages.

In most horizontally placed apparatus there is some difficulty in observing through the microscope. This has been eliminated in the large apparatus of Zeiss by the employment of two separate tables, one for the microscope and illuminating systems, and one for the camera.

The vertical form of apparatus has the advantage when photographing liquid preparations, and it obviates the necessity of swinging the instrument into the horizontal position every time it is used for photography. Also the slide will remain in focus by its own weight and the ordinary clamps of the stage. I find that most of the fine adjustments retain their foci better when the instrument is vertical. Since the vertical camera is usually short, the fine and coarse adjustments can be used without any extending rods or gearing for the purpose of focussing. The inevitable drawbacks to the vertical apparatus are first that a camera of limited length is almost compulsory. If one wishes to obtain a magnification of, say, one thousand diameters, using a 2-mm. objective and a No. 4 eyepiece, the camera screen must be about 50 cms. from the plane of the projection ocular, a distance which is only just within reach of the fine adjustment screw when the operator is observing the image on the screen. Again, it is much less fatiguing to focus when the image is vertical than when it is in a horizontal

position, especially when the head is enveloped in a focussing cloth.

Bearing these things in mind, I felt convinced that the ideal apparatus for high-power work lay in the combination of a vertically placed microscope with a horizontal camera. It is true that such an arrangement can be contrived with the most recent form of the large Zeiss apparatus, in which the camera can be racked up to a sufficient height to meet the eyepiece of the vertically placed microscope; but the whole apparatus is not only very expensive and cumbersome, but is of such a length that a fairly large room is required to use it with comfort. This apparatus also suffers in common with all other horizontal arrangements by the necessity of a gearing for the transmission of the fine adjustment motion to the operator's hand when focussing the image. However perfect the gearing may be, it cannot be trusted to keep in focus while the dark slide is being introduced, or until the exposure is complete. After having constructed and experimented with the two forms of reflex apparatus, I have adopted the following arrangement, which I have found most satisfactory. Fig. 27 shows the apparatus diagrammatically. A A′ is a strong table 25 mm. (10 inches) wide (shaded in the diagram). C is an asbestos-lined cover with changeable circular diaphragms in front. D is the usual condenser which collects the light to a point close to the mirror of the microscope. F is another stand to carry any further fittings, such as an auxiliary lens, or a trough with colour filter solution, etc. B B′ is a strong, rigid table, carrying G the microscope in a vertical position, upon a strong stool,

having at least 3 inches clear space below it. This clearance, together with the fact that the stool top is

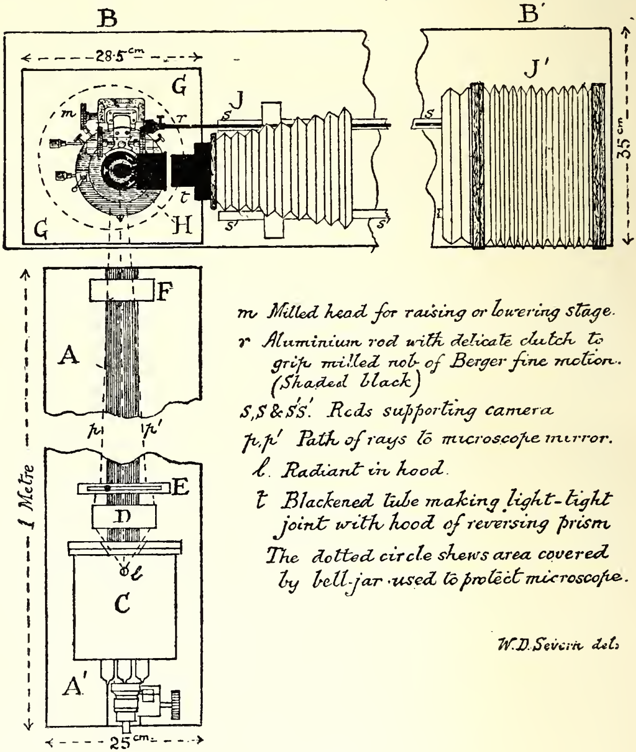
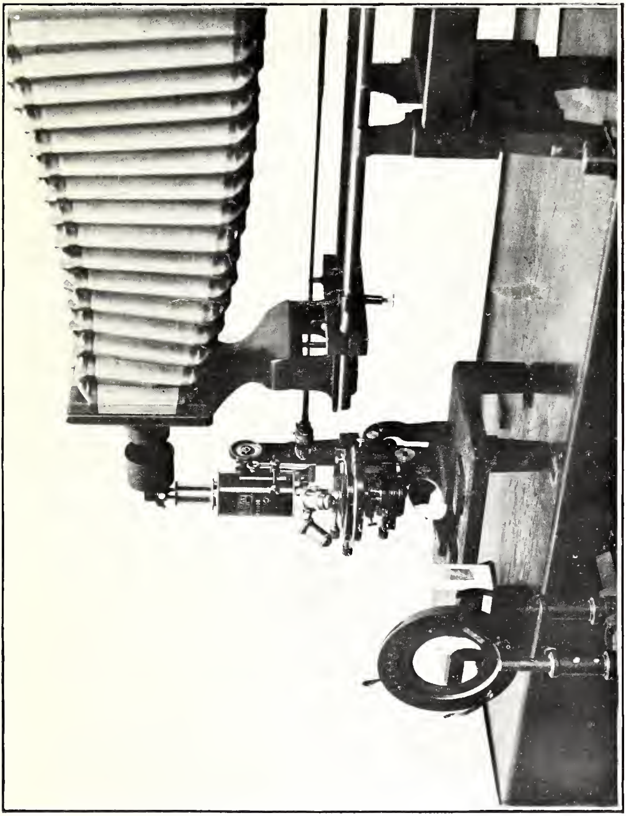


FIG. 27.

quite open between the feet of the microscope, will be explained later. H is a mount holding a small reversing prism with silvered hypotenuse at 45 degrees to the two optic axes, and provided with a blackened

PLATE XIV.



Another view of the central part of the apparatus for photomicrography.

[*To face p.* 228.

hood which makes a non-contact, light-tight junction with the camera front. J J′ is the camera made to slide on two round bars, so that it may be bodily withdrawn to a short distance from the microscope.

Another view of the central part of the apparatus is shown in Plate XIV. The camera is drawn back from the prism hood so as to show the rod leading to the slow motion behind the camera. In the foreground, on the optical bench, is an extra iris diaphragm as well as a tank for light-filtering solutions. The ordinary mirror of the microscope is in position.

This arrangement presents at least two great advantages. Firstly, the operator is enabled to sit comfortably at the point B, and perform any focussing or other adjustments with the microscope, thereby dispensing with a complicated revolving table, etc.

Secondly, a straight, light rod of aluminium or other metal can be instantly set in action with the small milled head of the Berger or other fine adjustment. It requires for this purpose only a very simple fitting. All gearing for transmitting the fine motion is therefore done away with, and, if only a small, cloth-lined V support be fitted near the observer's hand, the rod need not be lifted or lowered at all. Owing to the vertical position of the microscope, and the consequent elevated position of the camera, the aluminium rod passes beneath the camera to the right of its supports.

It will be found advantageous to have a cloth-lined gutter arranged alongside the apparatus to hold the rod when not in use, so that it may not sag or bend when at rest. A further advantage of this contrivance is that the microscope can be protected in a moment

when work is finished by simply covering it up with a bell-jar as it rests on the stool. The 3-inch clearance below the latter is to enable the first-surface mirror to reflect the light upwards. This enables a more perfect reproduction of the original beam of light to be formed, and also permits of longer patterns of aplanatic condensers to be inserted below the stage. Further, it allows of room for the insertion of an arrangement for the quick changing of colour filters. It is sometimes useful to arrange the three-colour screen of a Sanger-Shepherd repeating-back over the foot of the microscope, especially if it has a horseshoe stand. If a mirror be adapted below the stool it may be fixed exactly at 45, so that the light will remain permanently centred. Of course, in this case the optical bench must be correspondingly lowered. The whole arrangement can easily be constructed by any one with a little mechanical skill, the only precaution to be observed being that the camera supports at either end must be narrow enough to enable the slow-motion rod to pass straight on to the milled head. The rods which slide in supports with the camera are easily made from brass-plated curtain rods, but a solid bar of square or prism-shaped section would be preferable to the two round rods. The only objection to the form of apparatus above described is that there is no way of varying the height of either the microscope as a whole, or of the camera, to allow for the difference of focus of different lenses. This is not a serious objection at all, and can be easily surmounted by having a front to the camera which can be raised or lowered within a small distance, or else by slightly withdrawing or

closing the drawtube, and at the same time correcting the magnification by lengthening or shortening the camera. A still better way is to employ a microscope like the Zeiss pattern **I S**, in which the stage itself can be racked up and down independently of the rest of the microscope. This instrument is very solidly built, and for this reason is eminently suited for photomicrography, and it is to be hoped that British manufacturers will furnish some analogous form of stand.

Details relating to high-power colour photography.—The majority of high-power colour work consists of pathological and histological, and especially bacteriological preparations. Passing on to the actual subject of making photomicrographs in colour, I take it that the object of the great majority of operators in this field is not to produce transcendental ingenuities in colour for their own sake, but to represent as accurately as possible any microscopical preparations which they wish to place on record, or to demonstrate with the lantern. I shall write, therefore, from the point of view of the bacteriologist and pathologist. The majority of the preparations which a bacteriologist will wish to accurately represent are slide or cover-glass preparations of cultures or secretions stained in one colour. The colours will be either blue (methylene blue), violet (gentian or methyl violet), or red (fuchsine).

(1) The preparation is stained with methylene blue. Let us suppose a magnification of 1000 diameters is required. We take a rapid isochromatic plate (Wratten's isochromatic is strongly recommended for this

kind of work). Use a deep orange screen or a scarlet-red screen (Wratten's "G" screens superimposed answer well). Select a 2-mm. oil immersion apochromat or semi-apochromat of 1,4 or 1,3 N. A., and a No. 2 projection ocular. (By No. 2 we mean an ocular giving two magnifications.) The camera must be racked out to a distance of 100 cm. from the hypoteneuse of the inverting prism to the focussing screen. Of course, if a No. 4 ocular be used, the camera must be racked out 50 cm. It is a good plan to have a scale fixed along the whole length of the table marked out in inches and centimetres.

Exposure.—The tables for finding the correct exposure have already been given under the heading of low-power photography, and they apply equally well in this case. I may add, however, that with a radiant of about 750 cp., which I obtain with a star pattern triple filament (thick type) Nernst lamp, the exposure would be about 90 seconds for a bacterial culture. In all photographs of this nature the object is to get as great a contrast as possible, and in the negative the bacteria should appear as nearly clear glass, and the background as black as possible. We must therefore employ a contrast or hard developer. For this purpose I have found the following developer very efficient :—

Solution A.

Hydroquinone . .	9·5 grms.
Sod. sulphite . .	50 grms.
Citric acid . . .	3·5 grms.
Pot. bromide . .	3 grms.
Water	500 c.c.

Solution B.

Sod. hydrate (pure)	90 grms.
Water	500 c.c.

To develop take equal parts of A and B and add from half to an equal part of water.

Push development to the full, and fix thoroughly with acid hypo. It is always easy to clear up with hypo and ferricyanide of potash, by which the contrast will at the same time be increased. The negative having been obtained, make a clean positive on a lantern plate, clear if necessary, so that the background is perfectly clear glass. Wash thoroughly, and tone with the following toning solution:—

Potassium ferrocyanide . .	28 grams
Water	280 c.c.

Bleach the plate in this, and wash for ten minutes. Then place in Sanger-Shepherd's "Minus Red staining solution," 1 part to 2 parts water for $1\frac{1}{2}$ minutes. Transfer to hypo (1 to 5). Keep on applying fresh hypo until a clear blue image is obtained. Clear if necessary in sulphuric acid (1 to 300 water). Any other good blue formula may be used. Then wash well.

Now, if the original preparation had been stained with carbol-methylene blue, it will tend to be of a greenish-blue colour, and the lantern plate in its present stage will probably be a very accurate reproduction of it. If, however, the stain was an alkaline methylene blue (Loeffler), it will be more of a true spectrum blue. To obtain this the lantern plate should be dried, then soaked in distilled water, and flooded with very dilute nitric acid, and then again thoroughly washed. If there is any blue in the background, a very rapid treatment with dilute

potassium oxalate solution, followed by thorough washing, will remove it.

(2) In the case of a violet-stained film, proceed exactly as before, excepting that the light-filter may be of a lighter orange colour, without any green. One may use either two or three superimposed Wratten "G" filters, or a trough containing bichromate of potash solution of corresponding depth of colour, according to the intensity of the violet stain. Take a flat celluloid gelatine-coated film, sensitise in ammonium bichromate, or in the Sanger-Shepherd film-sensitising salt, and dry in the usual way, out of reach of dust and light. Then print this out with the uncoated slide against the film of the negative. Expose until details are visible as a pale silver image, or, better still, against a Chapman-Jones "Fraction tint actinometer." Expose simultaneously to the extent shown to be correct by previous trials. Then develop the film with warm water and dry. Make a solution of methyl or gentian violet (methyl violet 6B), called crystal violet, answers well. A 0·5 per cent. solution of crystal violet added to 100 c.c. of distilled water. Stain the film in this, and then wash until the bacteria appear deeply stained on a colourless ground. When dry, varnish with Sanger-Shepherd film varnish. The film will look better and clearer if mounted quite dry and warm between lantern cover-glasses in melted hard neutral Canada balsam. Wait until the balsam is quite dry, and then paint round the edge with hard asphaltum varnish. Bind up as usual. If it is desirable to add a circular mask in imitation of the microscopic field, which certainly adds

to the reality of the image, then omit the balsam on the celluloid side of the print, and insert the mask between the cover-glass and this side, after the balsam of the film-side is dry.

(3) In the case of a red-stained preparation such as a film of *B. Typhi*, or *Vibrio Choleræ* stained with fuchsine, a green screen must be used for making the negative, and the positive film must be stained in a solution of fuchsine. A suitable solution is made by adding 4 c.c. of a 0·5 per cent. solution to 100 c.c. of distilled water. Sometimes in examining a fuchsine-stained slide by daylight, the red colour may not appear so brilliant as that of the original preparation. This is because the dye fuchsine, or magenta, transmits a varying amount of blue in addition to the red rays, according to the makers' formulæ, or the manner of making the solutions. The yellow rays of the lantern will largely correct the slight proportion of violet in the red image. If further correction be desired, a little eosine (yellow shade) may be added to the fuchsine solution used for staining up. Lantern slides made as described above, when looked at through a blackened tube by transmitted light, give a remarkably exact reproduction of the picture seen, when the original preparation is examined under the microscope. Hitherto, only single-stained preparations have been considered, and it is very desirable to master the making of these before passing on to double and triple-stained objects.

A good simple example of double-stained high-power work is a film of tubercular sputum stained by the Ziehl-Neelsen method. In this process the tubercle

bacilli appear as brilliantly red minute rod-shaped objects, while the pus cells, débris, and other bacteria are stained blue. Put two Wratten "M" plates into a dark slide, and expose one of them under a green filter, and the other using a red filter. The first negative will show the tubercle bacilli very clearly marked, and must be printed on a gelatine film and stained up with fuchsine as directed for single-stained red preparations. The other plate will show only a faint image of the bacilli, but very distinct pus cells. From this negative a black lantern plate should be made, and toned as described for blue-stained preparations. As the gelatine film was printed through the back, if the two are placed face to face in register, a very good representation will be the result.

The following are the details of a successful two-colour slide of tubercular sputum stained by the Ziehl-Neelsen method on a slide 1 mm. thick.

Magnification.—1000-2 mm. Apochromatic oil immersion.

Condenser.—Centering achromatic N. A. 1·0 when used dry—used here oiled to slide.

Radiant.—Nernst lamp. Large projector 3 filament, star pattern, 220 volt—continuous.

1st "M" plate, Wratten B screen, 90 seconds exposure.

2nd "M" plate, Wratten A screen, 80 seconds exposure.

Developed with hydroquinone in total darkness for 4 minutes. There was a good deal of development fog which was cleared up by Farmer's reducer, resulting in very good negatives, except that there was a faint

image of the tubercle bacilli on the second plate. This, it was found, could be eliminated by using a liquid screen, in addition to the Wratten filter.

This liquid filter was made by adding 0·7 c.c. of a 0·5 per cent. solution of diamant fuchsine to 230 c.c. of water, and the thickness of the layer of fluid was 3 cm. The theoretical photographer may criticise the above results, in that a perfect negative was not at once obtained, and that accurate spectroscopic observations would have eliminated the necessity for a repetition of the second plate. Actual work with high powers will soon convince any one that practice often renders theory nugatory in colour microphotography, at any rate in its present stage of development. This is especially true in the matter of exposure under very high magnifications. An exposure of, say, a simple violet preparation under such conditions as I have indicated above, would work out under the theoretical formulæ at something like 600 seconds, whereas in practice an exposure of 80 or 90 seconds will generally yield a good negative, providing development is properly conducted. The study of absorption spectra is not only desirable for any one wishing to excel in colour photography, but, after working out all the conditions for any given preparation, the practical worker will often retreat to the primitive refuge of placing certain colour filters before his microscope condenser in succession, being guided by the visual results thus obtained. One must, of course, do this under the same light to be employed in taking the photograph.

In photographing sections stained by the old-fashioned methods of hæmatoxylin and eosin, great

difficulties will arise when one wishes to reproduce the colours with any exactitude. There is a table given in Messrs. Wratten and Wainwright's pamphlet on "Photomicrography," which gives the absorption spectra for three different hæmatoxylin formulæ; but all hæmatoxylin and hæmatein solutions change as they are kept in vitro, and sections stain all kinds of different shades, according to the alkali used to blue the preparation, and vary from other causes. It is not of vast importance that a lantern slide of a hæmatoxylin-eosine preparation should show pure blue and pink, and one may therefore adopt an artifice as follows: take the negative of a blue and pink hæmatoxylin section through a red or red plus orange screen, then develop, and print a black lantern plate. Tone the lantern plate as pure blue as possible, and stain up afterwards in weak eosin or erythrosin.

The *tout ensemble* is generally quite sufficiently realistic and educative, eosin being a diffuse counterstain at the best, and only fitted for blood studies. It is far otherwise when a section is stained by some method which entails delicate selective qualities. Suppose a section be stained first with Unna's polychromic methylene blue, then treated with differentiating agents, fixed and counterstained with orange-tannin mixture, and finally counterstained with acid fuchsin (Rubin S.). In the epithelial cells one may have a very red-violet tint, which becomes a peacock blue in certain secreting cells, while red blood-corpuscles become a bright orange, and the connective tissues a whole gamut of brilliant tints, to say nothing of accidental greens caused by the yellow elements in

the tissue combining with the blue of the stain. In such cases it is obviously necessary to resort to one of the three-colour processes; but, as has been pointed out, high-power work is seldom required for anatomical or pathological sections—at least, not over five hundred magnifications; but even with these magnifications, no one plate method will do. The grain of the plate is too coarse. Hence, for all such work, one of the three separate-plate methods is far superior. For the beginner it is much simpler to adopt the Sanger-Shepherd process as detailed in the booklet issued by the firm.[1] All the necessary apparatus can also be obtained from them for their processes, as well as for most of the other three-colour processes. It will be found that a plate 9 inches × 3 inches is quite large enough to make lantern slides from, and very little carpentering ability is required to adapt the whole arrangement to the back of the micrographic camera. Instead of finding the exposure ratios through the three screens by means of crumpled wool or a plaster cast, one must employ a black and white microscopic preparation, such as one of the old-fashioned micro-photographs of engravings, or part of a lantern slide diagram, or (for high powers) a stage micrometer. When the ratios have been found for any particular light and plate, it is only necessary to carefully follow the directions given in the booklet to obtain the finest slides possible. But it cannot be too much insisted on that the instructions issued by the company should be

[1] "Working Instructions for the Sanger-Shepherd Process of Natural Colour Photography." Sanger, Shepherd and Co., 5 and 6, Gray's Inn Passage, Red Lion Street, London, W.C.

rigidly adhered to, for, although many of the instructions may appear frivolous to the ordinary worker, the infringement of any one of them is apt to entail much disappointment and loss of time. In my opinion, the final cementing of the glass positive, the two celluloid positives, and the cover-glass is the most troublesome and tedious of all the stages, and the amateur must not be discouraged if he should fail at first in doing it to his satisfaction.

In conclusion, we would strongly recommend the following works on this subject, which we constantly refer to ourselves :—

(1) Spitta's "Photomicrography."

(2) Article by Dr. Duncan Reid, *British Jour. Phot. Almanac* for 1915.

(3) "Photomicrography," issued in pamphlet form by Messrs. Wratten and Wainwright, Ltd., Croydon, England.

(4) "Photomicrography" (Pamphlet). Kodak, Ltd., Kingsway, London, W.C.

(5) "Photomicrography," by Dr. E. C. Bousfield. J. & A. Churchill, London.

(6) "The Photography of Coloured Objects," by C. E. Kenneth Mees, D.Sc. Lond., published by The Eastman Kodak Co., Rochester, New York.

(7) "Handbook of Photomicrography," by Messrs. Hind and Randles. Routledge and Co., London, 1915.

CHAPTER XIV

ART IN COLOUR PHOTOGRAPHY

§ 113. **What constitutes Art?**—Unlike science, art is not governed by well-ascertained laws, but is largely a matter of education and individual taste. Of course it has its rules, and is governed by well-established principles; but when we come to special cases there is room for much argument and difference of opinion. In fact, the only branch of pictorial art which is based on rigid and undisputed rules is that of perspective. The more, therefore, we go into detail the more we must expect hostile criticism. Before dealing with art itself, it is necessary to have a clear understanding as to what we understand by colour, with its various hues and shades as applied to art.

§ 114. **Primary, Secondary, and Tertiary Colours.**—A long time ago Sir David Brewster pointed out that instead of Newton's seven colours, white light could be resolved into three, viz. red, blue, and yellow, and for this reason they were termed the three primary colours. Each was said to be the complement of the other two. Thus, red was said to be the complement of blue and yellow, yellow the complement of red and blue, and blue the complement of red and yellow. A mixture of any two was called a secondary

colour. Thus, green was a secondary of yellow and blue, and violet a mixture of red and blue. Consequently a mixture of all three in various proportions formed a tertiary colour. Scientifically this theory is entirely wrong, and this becomes very obvious when dealing with spectral coloured light, although true in the case of pigments. Hence, it is very convenient, and even necessary, when dealing with pigments. For instance, pigments mixed in certain proportions will form various shades of grey, which coloured lights never do. This fact is a most important point to remember in water-colour painting, and in retouching prints made from photographs by the three-plate method, or process blocks, and it will be found extremely useful in forming shadows over coloured parts. It was formerly believed that if pigments could only be obtained absolutely pure, that a pure white could be formed by mixing the three primaries in certain proportions. As a matter of fact, this can never be done, since in the sense formerly attributed to the word, every colour is a primary, *i.e.* every spectral coloured light can be mixed with some other coloured light which will produce white light. The following are the fundamental complementary pairs of coloured lights :—

Red	and	Blue-green (sea-green)
Yellow-orange	and	Blue (cyan blue)
Yellow	and	Violet-blue (indigo-blue)
Greenish-yellow	and	Violet
Green	and	Purple (red and violet).

Besides these fundamental complements, there are subsidiary complements, which are formed by pairing

intermediate shades of colour. We can illustrate this in a very convenient way by means of a chromatic circle. In this the colours of the spectrum are subdivided, so that twenty-four hues are shown in all

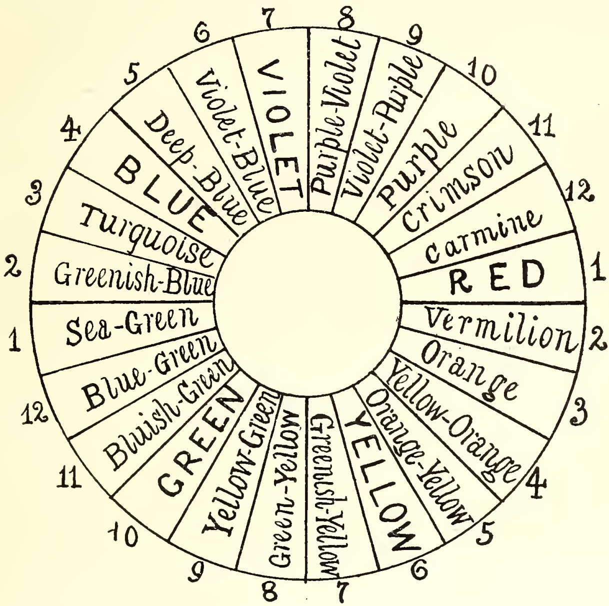


FIG. 28.—Chromatic circle showing the complementary pairs of colours, which are indicated by the same numbers.

which may be arranged in a circle corresponding to their actual position in the spectrum. In this circle it will be found that each colour is exactly opposite to its complementary, *i.e.* 180° away from it.

Although any two complementaries will produce the

sensation of white, it is not a true white, for Helmholtz pointed out long ago that the only two colours which would produce an absolutely pure white were yellow (or yellow-orange) and blue in certain proportions. If you examine the colour diagram you will observe that

	Violet.	Indigo-blue.	Cyan-blue.	Blue-green.	Green.	Greenish-yellow.	Yellow.
Red	Purple	Dark Rose	Light Rose	*White*	Whitish-yellow	Gold-yellow	Orange
Orange	Deep Rose	Light Rose	*White*	Light Yellow	Yellow	Yellow	
Yellow	Light Rose	*White*	Light Green	Light Green	Greenish-yellow		
Greenish-yellow	*White*	Light Green	Light Green	Green			
Green	Light Blue	Sea-blue	Blue-Green				
Blue-green	Sea-Blue	Sea-blue					
Cyan-blue	Indigo Blue						

Fig. 29.—Diagram showing the effect of Spectral Colour Fusion after v. Helmholtz.

green is the only colour which cannot find a partner to form white, or even an imperfect white, since the complementary colour to green is purple, which is a mixture of red and blue, and not a primary at all.

§ 115. As regards colour in art, we have to distinguish between hue, tint, and shade.

Hue.—This may be defined as an extremely narrow portion of the spectrum which corresponds to a definite wave-length, in other words, it corresponds to a certain definite colour. It corresponds to the pitch of a musical note. In a wider sense, it comprises a mixture of any pair of primaries in any proportion. Painters employ it in this sense.

Tint.—This is a hue diluted with white. The amount of admixture of white defines the tint. It corresponds to quality in the case of musical sounds. The addition of white will alter the tint without affecting the hue.

Shade.—This differs from a tint in that the hue is altered by the addition of black, or, indirectly, by varying the illumination. It corresponds to loudness when referring to musical sounds. For example, the hue "red" gives every variation of tint from red to white, and every variation of shade from red to black. Hence, a tint is any colour to which white has been added, a shade any colour from which white has been subtracted.

§ 116. **How one can shade or produce Shadows in a Coloured Drawing or Photographic Print in Colours.**—It is a common error with a beginner to imagine, if he wishes to make a *coloured* painting or print look darker or in shadow, he must add more colour and make it thicker. Making the colour thicker only makes it deeper in tint and more saturated; it never makes it darker or more in shadow. If he wants to make a colour darker, *i.e.* to place it in shadow, he must make it greyer. This can be done, *not by adding black paint*, however diluted with water, but by

painting over the surface with a mixture of the three primaries, in other words, a mixture of red, yellow, and blue paints in certain proportions, the proportions depending on the degree of grey or shade required. As a rule, much yellow, a little red, and more blue is required, and if one does this to any water-colour drawing, it will have the effect of being in shade. The best way to throw a light-yellow surface into shadow is to add a small quantity of red while the paper is still wet. This will give it an orange colour. Then add somewhat more blue paint. In the same way, in order to darken a blue surface, add some red, and then a good deal more yellow. For a red surface, wash over with a little blue, and then considerably more yellow. By varying the proportions of these three colours, you can obtain any shade you please. In each case the colours must be mixed on the paper. Instead of spreading the two-shade colours on with a brush, it often greatly improves the effect if the colours be *finely* stippled over. The dots are quite invisible at a very short distance, and the colours blend together, and, if well done, the effect is often most charming, giving rise to a very soft and delicate surface. Useful pigments for this purpose are[1]—

Yellows.	Reds.	Blues.
Chrome.	Burnt sienna.	Cobalt blue.
Gamboge.	Brown madder.	French blue.
Ochre.	Crimson lake.	Prussian blue.
Raw sienna.	Vermilion.	Ultramarine.
	Light red.	

[1] These colours are taken from Mr. H. A. Rankin's admirable little book entitled "The Teaching of Colour," published by Sir Isaac Pitman and Sons.

§ 117. **General Hints as to Colour.**—A few of the following hints may prove useful to the beginner in relation to this subject.

Always avoid very large areas of the same colour when taking a coloured photograph, as they weary the eye and detract the attention from the general composition. The more brilliant and prominent the hue, the smaller it should be in the case of a *coloured print*. But in the case of a *transparency*, very much larger areas may be employed with effect, owing to the light shining through the positive, and in this case the colours cannot be too brilliant.

Of all the colours, red, and especially a bright scarlet or vermilion, is the one which requires the greatest judgment in photographing. It is surprising how little red or orange there is in Nature, and especially in landscapes, if we except the red skies at sunset; and when it does occur, it is almost invariably toned down by a liberal admixture of browns, greys, and other sombre colours. I tested this by taking a large number of photographs through a spectrum-blue glass, which cut off all the red and orange rays, leaving the yellow, for the most part, unaffected. And I found, to my astonishment, that many of the prints showed very little difference from those taken on a panchromatic plate through a yellow screen, which, of course, is sensitive to all colours, including red and orange. Still, in almost every colour print, and certainly in every transparency, one or two large patches of bright red, together with others of a more sombre shade, greatly improved the effect.

It is well to remember that both bright red and

orange have a stimulating effect on the senses and exhilarate; bright sky-blues, nearly saturated, give a pleasing effect. On the other hand, very pale blues and light greys are anything but pleasing over large areas, while greens have a soothing effect and are especially restful to the eyes.

Large areas of white fatigue the senses and dazzle the eyes, whereas small areas have the opposite effect. As we have just stated, the amount of unmixed red in landscapes is so small that it is often advisable to shift the point of view so as to include if possible some considerable amount of red or other bright colour in the foreground or middle distance, in order to brighten up the picture. This is especially the case if the view is very largely made up of green foliage.

In order to make a pleasing picture, it is most important to see that whatever colour is dominant—by which we mean that it occupies the greater part of the picture—the colour should not be of the same uniform hue or shade, but that it should be repeated, or echoed, as it were, in various shades and tints throughout the picture, so as to give a sense of repose, while at the same time the main subject of the picture should have the most pronounced hue of all, so as to fix the interest on that spot. Every picture should exhibit unity of purpose throughout, as well as one and only one idea and episode, all the other parts being contributory and accessory to it. The composition of a picture is every whit as important in colour photography as in an oil or watercolour painting. No one will dispute the fact that a photograph of a house or cottage will have a more pleasing effect if

it occupies only a portion of the picture instead of the whole width, and that the house should be balanced by setting it off with a certain amount of foreground. Again, it will be far more artistic if the building be photographed from one side, so as to represent one of the side walls in addition to the front, instead of being taken horizontally so as to show merely the front of the house without any depth or sense of perspective whatever. No one with any artistic feeling will take a photograph of a road which stretches vertically up through the centre of the picture, nor will he set his camera right in the middle of the road, with the latter reaching nearly up to the lens, so that the print will exhibit a vast isosceles triangle of bare road cutting out the greater part of the view. He would certainly improve his picture if he raised his camera as high above the road as possible. By this means the nearest distance which forms the immediate foreground of the road can be photographed a very considerable distance away from the camera, so that the sides of the road would appear more nearly parallel, and thus produce a less violent perspective.

In order to contribute to depth, it is well to arrange the main lines of the picture obliquely, or more or less in diagonals to the sides. This will allow of a convergence of the perspective lines towards the vanishing point, as well as gradations in size of similar objects as they appear to recede, and this will largely add to the sense of depth. This is always an important element in a picture, because, in Nature, every object possesses three dimensions which in consequence give rise to a solid stereoscopic effect; whereas a

picture has of necessity only two dimensions, viz. height and breadth, and to give the sense of three dimensious, the artist has to create a number of illusions and contrivances. To this end he employs shadows, aerial effects, vanishing lines, contributory curves, and various other devices for increasing the sense of perspective and depth. Moreover, in colour photography, any colour can be intensified or reduced by local intensification or reduction, or the whole can be modified so as largely to contribute to these qualities.

§ 118. **Shadows.**—Shadows are especially useful in order to give depth and plasticity (stereoscopic effect) to the picture, and so remove the appearance of flatness which is so conspicuous a fault in most of the photographs made by beginners. This fault may be avoided —if there is no choice in taking the view—in a very simple manner by merely altering the position of the source of illumination, or if—as in landscape work—that is impossible, one must alter the direction of the view, so as to get the source of light more on one side. If that is of no use, one must wait until the sun occupies another position, or else defer taking the picture until the evening, when the shadows will be longer, and the high lights have diminished. The position of the sun is of paramount importance, and its effect on the picture should be a matter of careful study if you really wish to excel in your work.

Never photograph any one in a white dress, or indeed, a large, white object of any kind if it be illuminated by a light directly in front of it, *i.e.* behind the camera. Always secure a side light, or even one well above and in front of you, if the sun be sufficiently

high up to allow of the lens being cast into shadow. By this means you will be able to get as many half-tones as possible. White, unless in comparatively small quantities, is very unsatisfactory. In ordinary monochrome photography, it is easy enough to reproduce pure white over a surface of any size, but in colour photography it is almost impossible to secure a large, unbroken surface of pure white by combining the three primary colours. If, however, the surface is small, or largely broken up by half-tones and shadows, very pure whites may be reproduced and remarkably pleasing effects obtained. Beware of going to the other extreme, and allow black shadows to fall on the figure. This is especially important when photographing the face and other exposed parts.

Never take snow scenes with the sun directly behind, or you will get a flared picture with no half-tones, whereas, if the sun is nearly or even quite in front of the camera and fairly high up, the results are often magnificent, the snow and ice being full of lovely purple half-tones. But to secure this effect you must screen the lens from direct sunlight by means of a flap-shutter, or your hand or hat, or otherwise you will inevitably spoil the picture by the light striking the lens obliquely and causing flare and fog.

§ 119. **Choose Simple Subjects.**—The beginner is generally impressed by the beauty of a distant panoramic view, and naturally concludes that a colour photograph of what is spread out before him will make a most impressive picture. When he has taken and finished the picture, he is invariably disappointed with the effect produced. The reason for this is two-

fold. In the first place, the view which so enchanted him embraced an angle of about 150 degrees or more, whereas the actual angle of the picture taken only includes about 40 or at most 45 degrees; in fact, a mere slice of the panorama. No wonder that it proved disappointing. Again, unless a very large plate be used, everything in the far distance appears dwarfed, and all detail is lost, so that the eye wanders aimlessly over the picture without anything large enough for the eye to dwell upon with any satisfaction, since, unlike an ordinary photograph, it can only be enlarged with difficulty, and not at all if taken on a single colour-plate. The experienced photographer, on the other hand, will select a far more modest subject, often one which to the casual observer would appear entirely destitute of interest; such, for example, as a dripping well, set off with a group of ferns, or even an old rustic porch, or perhaps a bank covered with primroses. Such subjects would seem very commonplace, and he would certainly never dream of photographing them; and yet they are the subjects which are most frequently selected for a medal. Wherever possible, introduce figures, and see that they wear *bright* colours, and never black. Life of some kind, whether animals or human beings, always make a picture more interesting; they balance the surroundings, throw back the distance, and give strength and plasticity to the whole. But when you introduce figures into the landscape, don't on the one hand commit the fault of making the figures so small as to be lost in the landscape, nor, on the other hand, of placing the figures right in the fore-ground so as to reduce the landscape to a mere back-

ground of the figure. Of the two, this is by far the worst fault. In a landscape the figures should always be selected to harmonize with, and balance the picture. An inspection of Mr. H. P. Robinson's picture entitled, "Wayside Gossip," or of Gale's "Sleepy Hollow," reproduced in the former's little handbook of "Art Photography,"[1] will show what is meant.

It is also important to see that the colour of the dress harmonises with its immediate surroundings. Thus, a red parasol or cloak will often work wonders in brightening up a landscape. You must be sure and see that there is sufficient contrast to bring the figure into relief, so as to catch the eye at once. If, therefore, the person is wearing dark clothes, do not place him in the shadow or in front of dark foliage, or the broad trunk of a tree, but, rather, select a position in which the surroundings are as light as possible. A bright object placed next to a dark object or a deep shadow will make the bright one appear still brighter and the dark object darker. The more contrast the greater the prominence and the depth. Try and imitate Turner, Claude, or Cuyp, and employ every artifice to give the effect of depth and plasticity to your picture. A visit to the Turner room in the National Gallery will well repay a visit. Turner was in the habit of selecting some point such as the sun, which he placed above the horizon as the point of fixation, so as to give the impression of infinite distance, and all the objects in the foreground and middle distance he artfully arranged so as to direct the observer's eye towards this point.

[1] See "The Amateur Photographer's Library," No. 4. Published by Hazel, Watson, & Viney, Ltd., London.

One of the great secrets of pictorial photography is to endeavour to compensate and balance all leading lines and masses. If the lines incline in one direction, try and arrange the point of view so that other lines compensate by their inclination in a nearly opposite direction. By this means a sense of stability is secured, and the observer becomes unconsciously satisfied.

§ 120. **Portrait Photography.**—When taking a group, endeavour to arrange the figures so that they stand or sit down naturally, just as they would do if you happened to come upon the group unawares. If some of the persons are standing with their backs to the camera, or are sitting down, or happen to have their faces turned round in another direction, so much the better, as it will appear more natural. Very often the effect will be greatly enhanced by arranging the figures in an irregular, pyramidal group, with the heads at different heights, and the faces turned towards each other in a natural manner, as if in conversation. This idea is carried out to perfection in H. P. Robinson's celebrated photograph, "A Merry Tale," which will be found reproduced in the book referred to on a previous page. His work on "Picture Making by Photography" contains many illustrations which bear out in a graphic way the maxims I have laid down in this chapter.

Most amateurs, and even many professional photographers, are in the habit of arranging a group as if the members were drawn up on parade, with the result that there is no picture at all. One sees merely a row of individuals, all staring straight in front of them. This is a fatal mistake, and the further it is

departed from the nearer it will be to an artistic picture. Often a portrait taken with the back turned round so that the face is invisible in the camera, will actually be a better portrait, and more characteristic of the person, than a full-faced one. One of Whistler's greatest triumphs—a portrait of his mother—was taken in this way.

Let us take for example a photograph of a couple of children. The photographer who has no idea of art will place them side by side right in front of the camera, and staring into it like a couple of dolls, or else leaning their heads together in an idiotic fashion, while he sets the figures off by a hideously painted background, or, worse still, by a wall-paper decorated with endless baskets of impossible flowers. On the other hand, the artist will go to work very differently. He will think out some natural scene out-of-doors. Perhaps he will arrange the children playing at hide-and-seek on each side of a moss-covered trunk of a big tree, and just catch the expression of the one looking round the corner with the face in full view and laughing merrily, while the other has its face turned partly away, and is peering round the opposite side of the tree. Or he may photograph them unawares, sitting down on a bank or under a hedge gathering blackberries or buttercups, which they are busy placing in a basket. What could be more charming than the picture of two children by Millais, entitled, "Cuckoo"? This is art, because it illustrates a scene in their real lives. They are doing something which they are accustomed to do, in a natural manner and without any pose. All that is required in either case is to

arrange the dress surroundings and illumination so as to harmonise perfectly, and quietly await the opportunity when the children are unconscious that their portraits are being taken, and as a result you will have a real picture. I recollect seeing in one of the photographic exhibitions in London a photograph of a number of fishermen and boys leaning over a sea-wall with some shipping in the background. It was called "A Stern View," and hardly a single face could be seen. But this picture was wonderfully true to life, and was so excellent that I believe it was awarded a medal. It cannot be too often repeated that unless you mix brains with your colours, whether in a painting or a photograph, it will fail to have much value. Although a photograph is incapable of producing the full individuality of the artist, nevertheless a colour photograph will always contain evidence of the photographer's soul and inspiration in every part of the picture, if it is to rank as a really artistic production.

§ 121. **Backgrounds.**—A suitable background greatly adds to the beauty of any coloured object which may be selected for reproduction. Pottery, flowers, fruit, fish, butterflies, and other natural objects will often appear tame and commonplace without a background, or with an unsuitable one, but will be made beautiful and striking when shown up by an artistic background. If the object requires a strong relief, a very dark twill, or, even better, a piece of black velvet or velveteen, will do admirably, provided the object be light in colour, and especially if it is a bright yellow or orange. On the other hand, a dark object, or one showing a fully saturated colour, such as crimson, emerald green,

or Prussian blue, will show up best against a creamy or bluish-grey background. It is rarely advisable to select the exact opposite or complementary colour, but, as we have already mentioned, a hue some 20 or 30 degrees away from the opposite side of the chromatic circle of colours (see Fig. 28) may with advantage be chosen. The complementary colour generally affords too severe a contrast to blend harmoniously with the subject.

Sometimes the same hue in a much darker or lighter shade is pleasing. Often greys, browns, or some other neutral or composite hue will serve the purpose best. As a rule, a simple colour without any pattern should be chosen. The reason for this is that any pattern, however inconspicuous, will, to some degree, draw the observer's attention away from the subject of the picture. It is, however, quite permissible to vignette the background, or vary the tint or shade over certain parts. In many cases, should strong relief be desired, the light should be so arranged that the object will cast a deep shadow over a portion of the background. This, of course, can be readily effected by arranging the lighting so that it emanates from one side only, the rest of the room being more or less in subdued light.

The backgrounds which I can recommend from experience are brown, light-brown, pale-green, dark-green, and dark-blue twill, or stiff linen cloth, which should unroll quite flat, without any creases. Also red, purple, and cream-coloured velvet or velveteen are most useful for exhibiting many brilliant objects such as jewels, coins, butterflies, and beetles, etc.

These show up splendidly by contrast on cream or coloured velvet, and they can be made to appear in high relief by shutting out all superfluous light and confining the illumination to one side of the object, so as to cast deep shadows.

APPENDIX

Theories of Colour Vision.

Several theories have been made to explain the phenomena connected with colour vision. But none of them will explain all thc facts, although each of them in turn has its special advantages. The two theories most in favour are those known as the Young-Helmholtz and the Hering theories.

1. *Young-Helmholtz theory.*—This theory, which was originally suggested by Thomas Young about the year 1807, and slightly modified by Helmholtz, assumes that there are three types of nerves in the retina, each tuned to respond to one of the three primary colour sensations, viz.—red, green, and blue-violet. By decomposition of the three photo-chemical substances stored up in the retina, the nerve fibres are stimulated to respond to the frequencies of vibration corresponding to these colours. These vibrations generate impulses in the nerve ends which are conveyed to the visual centres in the grey matter of the brain, and the mind perceives the colours developed.

By suitable mixing of these three colours, every shade and hue can be produced. Thus White is the result of the fusion of all three colour sensations, or of any two complementary coloured lights, while Black

on the other hand results from the absence of all stimulation of those parts which are capable of responding to colour stimuli.

Helmholtz constructed a scheme to illustrate the effect of stimulating the photo-chemical substances which produce the three colours in different degrees according to the different colour observed. Thus yellow will be produced by the fusion of much red and green, together with a trace of blue; while blue is caused by the full stimulus of blue substance with a

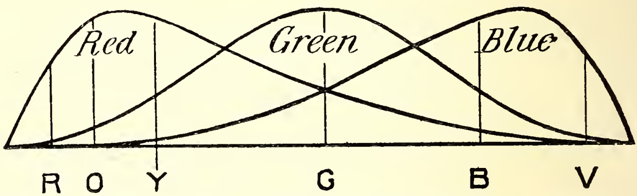


FIG. 30.—Scheme illustrating the Young-Helmholtz Theory of Colour Vision.
The curves represent the intensity of stimulation of the three colour substances.

little green and a mere trace of red. It will be noticed from the annexed figure (Fig. 30) that it is impossible to stimulate any one of the primaries without at the same time affecting to some extent the other two.

Unfortunately, if we try to imitate in practice any of the colour sensations in the same proportions as the curves in Helmholtz's diagram, an almost colourless or dirty white will result. Hence some physiologists have suggested that the curves should take a different form.

There are many objections to the Young-Helmholtz

theory in addition to those mentioned in § 22. Thus we are not conscious that the sensation of white is a blend of two or more colours, as we invariably are in such mixtures as peacock green or purple. Again, towards the periphery of the retina we can perceive whites and greys notwithstanding that part is colour blind. Moreover, we perceive black as a real impression, although Helmholtz explained it as being due to a state of quiescence or rest of the visual cells.

2. *Hering's theory.*—This theory also assumes three photometric substances which give rise to six different qualities of sensation, arranged in three pairs, one sensation in each pair undergoing assimilation, while its fellow undergoes disassimilation. Thus we have a white-black substance, which when acted upon by light undergoes disassimilation, and gives rise to the sensation of white, while the same substance becoming assimilated gives rise to a black sensation. In the same way a red-green substance and a yellow-blue substance exist in the retina, each of which by assimilation or disassimilation results in the sensation of one of its components. These six sensations can be tabulated as follows:—

Photochemical substance.	Retinal process.	Sensation.
Red-green . .	Disassimilation	= Red.
	Assimilation	= Green.
Yellow-blue . .	Disassimilation	= Yellow.
	Assimilation	= Blue.
White-black . .	Disassimilation	= White.
	Assimilation	= Black.

This theory gives a definite objective cause for the sensation of white, black, and yellow, and in this respect is superior to the Young-Helmholtz theory. It

also accounts for yellow as a distinct sensation which the physiologists demand. Moreover, it is in harmony with the fact that in certain birds and reptiles we find yellow as well as red oil globules in the bacillary layer, and also in the majority of tapeta we find not only red and green but also intense yellow colours over large areas. Instead of complementary colours red and green should be termed antagonistic colours. When they act simultaneously on a retinal cone, the effects

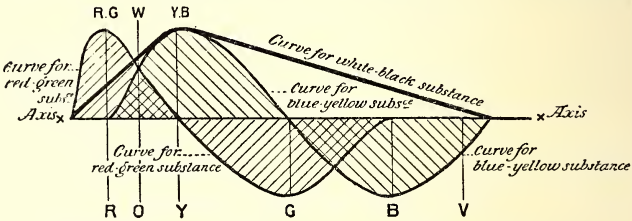


FIG. 31.—Scheme to illustrate the Hering Theory of Colour Vision (after Foster).

The curves above the axis, *xx*, illustrate catabolic changes (disassimilation), those below the axis anabolic changes (assimilation).

neutralise one another and the result is white, or, as Heron would say, the disassimilation effect remains over which produces white. It will be seen from the above description that the Young-Helmholtz theory agrees best with physical, while Hering's theory agrees best with physiological, phenomena.

1. Table of Exposures for Separate and Combined Colour Plates

The following table giving approximately the correct exposures for the Autochrome, Omnicolore, and Paget plates, has been revised by Messrs. Lumière, Messrs. Jougla, and Mr. Dawson respectively, to which the Dufay has been added. The ratio of the five plates with their proper filters is as follows in seconds (″) or in minutes (′).

Autochrome 1″, Dufay $\frac{3}{4}$″,[1] Omnicolore $\frac{3}{5}$″, Paget separate plate $\frac{1}{3}$ to $\frac{1}{4}$, or taking the Paget separate plate as unity, we get—

Paget separate 1″, Omnicolore 5″, Dufay 4″, Autochrome 3 to 4″. The following table gives the exposures between the middle of May and middle of August, with lens working at F/8 and time of day 10.30 to 2.30. Bright sky, white clouds or sun. In cloudy weather increase exposure 3 to 6 times.

For the benefit of those who do not understand ratio-apertures, the following table will be found useful. If we assume the exposure with a stop of F/8 = 1 sec., then—

F/4	requires	$\frac{1}{4}$	sec.
F/5, 6	,,	$\frac{1}{2}$	,,
F/6, 3	,,	$\frac{2}{3}$	,,
F/6, 8	,,	$\frac{3}{4}$	,,
F/8	,,	1	,,
F/11	,,	2	,,
F/16	,,	4	,,
F/22	,,	8	,,
F/32	,,	16	,,

[1] According to the Author's experience Dufay plates should have $1\frac{1}{4}$″ and Omnicolore $1\frac{1}{2}$″, *i.e.* slightly longer exposure than the Autochrome.

Subject.	Bright sunshine 10.30–2.30, May 15–Aug. 15, F/8.			
	Omnicolore.[1]	Dufay.[1]	Autochrome.	Paget.
Portrait or flower study, well lighted room near window with white reflector	30″–60″	25″–50″	20″–40″	7″–15″
Portraits, flowers, fruit studies, studio well lighted . . .	15″–25″	12″–20″	10″–16″	3″–5″
Ditto, ordinary room not near window .	4′–6′	$3\frac{1}{2}$′–5′	$3\frac{1}{2}$′–5′	1′–2′
Ditto, ditto, in open air, bright sunshine	4″–6″	$3\frac{1}{2}$″–5″	$3\frac{1}{2}$″–5″	1′–2′
Stained-glass window north aspect with much ruby glass.	45″–80″	35″–60″	27″–48″	9″–16″
With addition of K1 filter to the lens .	3′–5′	2′ 30″–4′ 30″	2′–3′ 30″	40″–80″
Open landscape, no heavy objects in foreground, well lighted	1″–2″	$\frac{3}{4}$″–$1\frac{1}{2}$″	$\frac{3}{5}$″–$1\frac{1}{4}$″	$\frac{1}{5}$″–$\frac{2}{5}$″
Ditto, strong foreground	$3\frac{1}{2}$″–7″	3″–6″	$2\frac{1}{2}$″–5″	1″–2″
Ditto, very heavy foreground . . .	10″–20″	9″–18″	6″–12″	2″–4″
River view, water in foreground, no dark objects, well lighted	$\frac{1}{2}$″–1″	$\frac{3}{8}$″–$\frac{3}{4}$″	$\frac{1}{3}$″–$\frac{2}{3}$″	$\frac{1}{10}$″–$\frac{1}{5}$″
Open lake or sea view, sun or bright light on water . . .	$\frac{1}{4}$″–$\frac{1}{2}$″	$\frac{1}{5}$″–$\frac{2}{5}$″	$\frac{1}{6}$″–$\frac{1}{3}$″	$\frac{1}{20}$″–$\frac{1}{10}$″
No large objects near, with addition of K1 filter	$2\frac{1}{2}$″–$4\frac{1}{2}$″	2″–4″	$1\frac{2}{3}$″–$3\frac{1}{3}$″	$\frac{1}{2}$″–1″
Snow and ice scene .	$\frac{1}{4}$″–$\frac{1}{2}$″	$\frac{1}{5}$″–$\frac{2}{5}$″	$\frac{1}{6}$″–$\frac{1}{3}$″	$\frac{1}{30}$″–$\frac{1}{15}$″
No dark rocks, well lighted, with K1 filter added . . .	2″–4″	$1\frac{4}{5}$″–$3\frac{1}{2}$″	$1\frac{1}{3}$″–$2\frac{2}{3}$″	$\frac{3}{8}$″–$\frac{3}{4}$″
Ditto, ditto, in winter, much snow, and K1 filter added . .	4″–8″	$3\frac{1}{2}$″–7″	$2\frac{2}{3}$″–$5\frac{1}{2}$″	1″–2″

[1] According to the Author's experience, the exposure of the Dufay and Omnicolore plates should be, if anything, longer than that of the Autochrome. If the exposure of the Autochrome be taken as 1″, that of the Dufay should be about $1\frac{1}{4}$″, and the Omnicolore $1\frac{1}{2}$″. The exposure of a Paget plate is about one-third that of an Autochrome.

Stained glass windows with much ruby glass require a very full exposure, or the reds will appear brick-red and weak. All ice and snow and seascapes require a second filter to suppress the excess of violet light; Wratten's K1 will do. It should be fixed in front of the lens during exposure. A K2 filter[1] or a second Lumière filter held in front of the lens during one-half of the exposure is recommended by some workers.

2. Table of Exposures of Sunsets for Autochromes (*V. Crémier*).

60 minutes before scheduled time of sunset (F/8)	1½ secs.
45 ,, ,, ,, ,,	3 ,,
30 ,, ,, ,, ,,	6 ,,
15 ,, ,, ,, ,,	12 ,,
5 ,, ,, ,, ,,	22 ,,
At sunset	30 ,,
5 mins. past	2 mins.

[1] These filters can be obtained from Wratten and Wainwright, Photographic Plate Manufacturers, Croydon, England.

3. Table of Additive Colour Effects, or Colour Synthesis (*Helmholtz*).

Colour.	Violet.	Indigo.	Cyan-blue.	Blue-green.	Green.	Greenish-yellow.	Yellow.
Red	Purple	Dark Rose	Light Rose	*White*	Whitish-yellow	Golden-yellow	Orange
Orange	Dark Rose	Light Rose	*White*	Light Yellow	Yellow	Yellow	
Yellow	Light Rose	*White*	Light Green	Light Green	Greenish-yellow		
Greenish-yellow	*White*	Light Green	Light Green	Green			
Green	Light Blue	Sea-blue	Blue-green				
Blue-green	Deep Blue	Sea-blue					
Cyan-blue	Indigo						

4. Table of Relative Brightness of a Strongly Illuminated Spectrum (*Vierordt*), Yellow-green being considered as 100.

Red	2
Orange	12
Yellow	78
Yellow-green	100
Green	37
Blue	12·8
Dark blue	0·8
Violet	0·07

5. Slowest Exposures necessary to secure Sharpness.

Conditions.—Focal plane or other highly effective shutter. Lens, 5 to $6\frac{1}{2}$-in. focus. Nearest object, 50 feet.

	sec.		sec.
Ordinary street scenes with traffic. No rapid motion	$\frac{1}{5}$	to	$\frac{1}{10}$
Trees, moving with light breeze	$\frac{1}{25}$	to	$\frac{1}{50}$
,, ,, ,, strong wind	$\frac{1}{200}$	to	$\frac{1}{300}$
Yachts, motor boats, 10 knots per hour, viewed end on	$\frac{1}{20}$	to	$\frac{1}{30}$
,, ,, ,, ,, broadside on			$\frac{1}{150}$
Trains, 30 miles an hour, nearly end on, beyond 50 ft.	$\frac{1}{60}$	to	$\frac{1}{100}$

For trains nearly broadside on, motor-cars, horses galloping, divers, birds on wing, etc., all calculations are useless. You must use quickest shutter, and largest diaphragm compatible with density of negative and sharpness of image.

With F/4 aperture and bright sunlight in June and July between 11 and 3, ordinary street scenes beyond 50 ft. can be taken with $\frac{1}{10}''$ exposure on Paget (separate) plates. If the plates be resensitised by Grant's method, an exposure of $\frac{1}{20}$ sec. can be given with F/4 stop.

6. Factor Numbers (*Watkins'*).

Developer. Temperature 60° F. to 65° F.	Factor.		
	Soft.	Normal.	Hard.
Adurol	4	5	6
Amidol[1]	7	10	12
Azol (Johnson)	20	30	35
Diogen	8	12	15
Dionol (Diamidophenol)	44	60	75
Edinol	14	20	25
Eikonogen	8	12	15
Glycin (soda)	6	8	10
,, (potash)	9	12	16

[1] Amidol (2 grains to the ounce) has according to some writers a factor of 18 for normal contrast, and Pyro Metol 14.

The "Agfa" Co. give the following factors: Amidol 18, Eikonogen 9, Glycin 10, Hydroquinone 5, Pyro-soda 5, Imogen-sulphite 5, Metol 30, Metol-hydroquinone 14, Ortol 10, Rodinal 30.

Developer. Temperature 60° F. to 65° F.	Factor.		
	Soft.	Normal.	Hard.
Hydranine	5	7	9
Hydroquinone	3	4·5	5
Imogen	4	6	8
Kachin	7	10	12
Kodak powders	13	18	23
Metol (Hauff)	20	30	35
Metol-hydroquinone	10	12	15
Metaquin	9	12	14
Ortol	7	10	12
Paramidophenol	12	16	18
Paraphenylene	20	25	30
Pyro-catechin	7	10	12
" " (Crystals)	22	30	35
Pyro-metol	6	9	11
Pyro-soda without bromide 1 gr.	13	18	22
" " " 2 "	9	12	14
" " " 3 "	7	10	12
" " " 4 "	6	8	10
" " " 5 "	5	6½	8
Pyro-soda with bromide (half the above factors)	—	—	—
Pyro-soda (Imperial)	4	4¾	5½
Quinomet	9	12	14
Rytol (Burroughs Wellcome & Co.)	10	12	15
Rodinal	30	40	50
Synthol	22	30	35

Note.—The factor (at least in the case of Pyro and Amidol) varies inversely with the percentage amount of the active ingredient, and inversely with the amount of restrainer (Bromide, etc.).

The factor governs the contrast thus: For more contrast, use a higher factor; for flat negative, or soft contrast, use a lower one.

Roughly speaking, for soft contrasts use three-fourths of the normal factor; for strong contrasts, add one-fifth to the normal factor.

Example.—Metol-hydroquinone is used as the developer. The image first appears after 20 sec. Since the factor is 12, the plate must be left in the developer for 20×12 sec., *i.e.* 4 min. If soft contrast be desired, the plate must be left in for 20×9 sec. = 3 min., and for hard contrasts, for 20×15 sec. = 5 min.

Rule for factor developing.—Multiply the number of seconds that have elapsed between pouring on the developer and the first appearance of the image by the factor number. The product gives the time that the plate should remain in the developer.

Double emulsions, such as Cristoid films and Thomas's plates, require at least double the time of the factor. Other plates, whether slow, fast, or isochromatic, do not appear to affect the result.

Rule for combination developers.—If equal quantities of each be used, half the sum of the two factors will be the factor of the mixture. If the mixture contains unequal parts, proceed as follows:—

Let f = factor – number of solution A;
f' = factor – number of solution B;
x = number of ounces of A;
y = number of ounces of B.

Then the combined factor number

$$F = \frac{fx + f'y}{x + y}$$

Example.—A mixture is made of 4 oz. of hydroquinone and $1\frac{1}{2}$ oz. of metol. What is the combined factor F? The factor of hydroquinone is 5, that of metol is 30, therefore

$$F = \frac{fx + f'y}{x + y} = \frac{4 \times 5 + (1\cdot5 \times 30)}{5\cdot5} = 12 \text{ (approx.)}.$$

This does not hold strictly true with pyro developers, which affect the speed of other developers in a different way.

As regards the ultimate image, all developers appear to give the same, or nearly the same, result, but the rate at which the image first appears, as well as the time necessary to acquire a standard density and gradation, differ enormously.

Thus, in the case of rodinal, metol, and dianol (diamidophenol) the image flashes out quickly, but it requires to be developed for a long time in order to acquire sufficient density, while, in the case of strong pyro-soda, adurol, and hydroquinone, the image takes a long time before appearing, but requires a short development to secure the necessary density.

INSTRUCTIONS FOR DEVELOPING AUTOCHROME PLATES.

7. Pyrogallol Developer for Autochrome Plates.

Some operators still prefer Lumière's "Pyro" developer, which is as follows—

1*st Development* (*Stock Solutions*).

AA.	Sod. Bisulphite (commercial solution) .	2 drops
	Pyrogallol (dry)	3 grms.
	Bromide of Potassium	3 ,,
	Distilled water	100 c.c.
BB.	Anhydrous Sodium Sulphite . . .	10 grms.
	Ammonia (0·923 or 22 B)	15 c.c.
	Distilled water	85 c.c.

For a half-plate take equal parts of AA. and BB. (10 c.c. of each) and add 100 c.c. (3½ ozs.) of distilled water.

Develop (if correctly exposed) for $2\frac{1}{2}$ minutes at a temperature of about 60° F. This bath cannot be used a second time.

2nd Development.

Diamidophenol	0·5 grms.
Anhydrous Sodium Sulphite . .	1·5 ,,
Distilled water	100 c.c.

Leave positive in this bath in full daylight from 3 to 4 minutes or more. Wash and allow to dry.

8. Lumière's Formula (1908).

Quantities sufficient for whole plate or $7\frac{1}{2} \times 5$ plate.	Time of action.	Remarks.
A.— Quinomet, 1·5 gms. (23 grns.)[1]	$2\frac{1}{2}$ min. for correct exposure	Image should appear in 10 to 14 seconds.
Water (distilled) 100 c.c. ($3\frac{1}{2}$ oz.)		Factor = 12.
Sodium Sulphite, 10 grms. (154 grns.) Potassium Bromide, 0·6 gm. (9 grns.) Ammonia (density 0·923) 3·2 c.c. (55 m.)	Temperature of baths 15° C. (60° F.)	Hence time of development = No. of secs. before image first appears multiplied by Factor. Thus, if image appears after 13″, then 13″ × 12″ = 156″ or $2\frac{1}{2}$ min. (approx.). Wash 1 min. in dark.

Dissolve the Quinomet in the water, add the Sulphite and Bromide, then the Ammonia.[1]

AA.—For use. To one part of A add 4 parts of water (preferably distilled).

[1] Quinomet is another name for Metoquinone, and is a chemical compound and not a mechanical mixture. It consists of Metol in powder 6·2 gms., Hydroquinone 8·8 gms. It is sold in a solid form by the Lumière Co.

Quantities sufficient for whole plate or 7½ × 5.	Time of action.	Remarks.
B.—*Reversing bath*— Potassium Permanganate, 0·2 grm. (3 grains) Sulphuric Acid 1 c.c. (17 m.) Water, 100 c.c. (3½ oz.)	2–4 min. according to appearance of image as observed from time to time in daylight	After plate has been in B for ½ min., the dish may be carried into full daylight and the transparency examined. Wash for 1 minute in several changes of water.
C.—*Redevelopment*— Plate is returned to AA bath	4 min.	Must be carried out in full daylight or negative must first be exposed six inches in front of 1 ft. of Magnesium ribbon. Wash 2 mins.
D.—*Hardening and clearing bath*— Powdered Chrome Alum, 6 grms. (90 grns.), or alum 6 grms., Citric Acid in powder 0·6 grm. (9 grns.) Tap water, 4 ounces. Quantities need not be measured.		This bath is optional, but brightens up and toughens the film. Wash 2 minutes. Then leave to dry. Fixing in Hypo optional. (Wash 3 minutes.)

Or instead use a 1/500 bath of Permanganate of Potassium (without acid). This is preferred by Lumière to the alum and citric bath. In hot weather Chrome Alum must be used.

9. Lumière's Improved Graduated Developer for Uncertain Exposures (Latest Formula, 1910).

This developer allows of greater latitude in exposure than the last mentioned. The other baths remain the same.

Solution 1.—Place in glass measure (for a quarter-plate or 5 × 4) 40 c.c. (1 fl. oz. 2 drms.) of water. Add Quinomet (concentrated developer) 2·5 c.c. (42 m.). Call this A.

Temperature about 15° C. (60° F.).

Solution 2.—Also in a second (small) measure put 7·5 c.c. (2 drms. 8 m.) of concentrated developer. Call this B.

Place your watch close to green (Virida paper) safelight.

Put plate in dish in nearly total darkness, and pour developer A over it the moment the second hand reaches 60 seconds. Rock the dish (screened from the light) for 14 seconds, then bring the dish containing plate close to the light for a moment to see if a trace of the image has begun to appear (ignoring sky). The moment this occurs note number of seconds which have elapsed. Then add immediately contents of small measure (B) while rocking dish. Put cover over dish and consult the following table, which you should have previously written in Indian ink on the outermost Virida paper of the lamp.

If time which has elapsed since first appearance of image is	Development should be continued (from the commencement) for minutes.	seconds.
12″ to 14″	1	15
15″ to 17″	1	45
18″ to 21″	2	15
22″ to 27″	3	0
28″ to 33″	3	30
34″ to 39″	4	30

If image fails to appear after 40″, add 22 c.c. of Quinomet solution (B).

	minutes.	seconds.
40″ to 47″	3	0
48″ to 60″	4	0

If no image appears at the end of a minute, the plate is hopelessly under-exposed. Then wash in the dark, place in reversal bath and redevelop according to instructions given in Table 8. If after reversal the image looks heavy and dull, *i.e.* wanting transparency, it shows under-exposure. This can sometimes be partly remedied by placing for a moment in a fresh hypo bath and looked at frequently, until the colours are more transparent. Then wash well, redevelop, and intensify.

In hot weather, or if temperature of the solutions exceeds 68° F., use Chrome Alum bath immediately after reversal to prevent frilling.

Reduction or intensification is preferably carried out immediately after the redevelopment (before positive has begun to dry). After intensification it must be immersed in the fixing bath, otherwise the latter bath may be dispensed with. If the second development has not been very thorough, and no intensification performed, fixation had better be omitted, as there is risk of producing a flat, dull image.

As Professor Namias's modification of Lumière's formula is very highly spoken of by many amateurs, I give it here.

9A. Professor Namias's Method of Developing Autochromes.—Make the following stock solution :—

Soda sulphite (crystals)	100 grms. (or 2 oz.)
Ammonia 22 per cent. (Beaume) .	32 c.c. (4½ drams)
Pot. bromide	6 grms. (54 grs.)
Metol	4 grms. (35 grs.)
Hydroquinone	12 grms. (105 grs.)
Water	1000 c.c. (20 oz.)

After reversal, clear in the following solution :—

Potassium ferricyanide 3 per cent. solution .	50 c.c. (3 oz.)
Ammonia	4 ,, (2 drms.)
Hypo 10 per cent. solution	50 ,, (3 oz.)

Dilute with twice its bulk (200 c.c.) of water.

Intensify by the mercury method :—

Bichloride of mercury	0·5 grm.
Common salt	1 ,,
Hydrochloric acid	a few drops
Water	100 c.c.

Then rinse well and re-develop in the original developer. If less effect be desired, use a 5 per cent. solution of sodium sulphite. In commencing development Professor Namias uses two baths (1st) 5 c.c. of the above-mentioned stock solution to 50 c.c. of water, and (2nd) 20 c.c. of stock solution to 80 c.c. of water. He immerses in first solution to find the time which has expired before the image begins to appear (neglecting the sky), and then he immediately puts the plate in the second solution and develops by Lumière's table (*vide* previous section, p. 273, Table 9).

10. Other Developers.

Instead of the Pyro or Quinomet solutions, Rodinal may be used, diluted 1 to 5 of water for under-exposed plates, or 1 to 6 for normal exposures, and 1 to 15 or 1 to 20 for over-exposed plates. Develop for about 2 minutes, or, with diluted developer, for 4 to 8 minutes. Rodinal is a very powerful developer, and is eminently suited for travelling, as it occupies so little space. Ordinary tap water may be used. Of course, any

one of the developers mentioned in the Table of Factor Numbers (No. 6) may be used, and the time of development regulated by the factor number. Among those specially recommended are Metol-hydroquinone (Meto-quinol), Glycin, Rytol, and Rodinal (1·20 or 1·30 of water). This last developer is highly recommended and very useful for travelling, as it takes up no room and requires no acceleration.

The Author has discarded Lumière's graduated development method and prefers Meto-quinol, using 12 as the factor number. He covers the dish with a card the moment the image begins to appear, and does not uncover it until at least two-thirds of the time has elapsed.

11. Intensification Formulæ.

Lumière recommends the following :—

(1)	Pyrogallic Acid	3 grms.	Label F.
	Citric Acid	3 grms.	
	Distilled Water	100 c.c.	
(2)	Nitrate of Silver	5 gr.	Label G.
	Distilled Water	100 c.c.	

For use, take 5 c.c. of G and add 5 c.c. of F; pour into 50 c.c. of distilled water. Pour this over positive, and rock until colours are sufficiently bright, or until the solution becomes turbid. Be sure you use the solution the moment you have added the silver to solution F, for precipitation of the silver commences in about half a minute, and the solution becomes black and useless.

Another excellent method is :—

(1)	Perchloride of Mercury	½ grm.
	Common Salt	1 grm.
	Water	100 c.c.

(2) Sulphite of Soda (Cryst.) . . .	5	grms.
Water	100	c.c.

These baths may be used repeatedly.

Leave plate in (1) until the image is completely whitened. Wash for a minute and place in sulphite solution. The process may be repeated if more intensification be required, and one may either redevelop with amidol or metol-hydroquinone developer, or 1 % of strong ammonia solution may be used instead of the sulphite bath. This gives a very black image. Then fix in hypo.

Either of the above methods can be used to intensify the image or any of the plates mentioned.

As soon as the image has been intensified it must be fixed in hypo, since during intensification in either method a silver compound is formed which will be acted upon by the light.

12. Reduction Formulæ.

(1) Either use the acid permanganate or the acid bichromate reversal bath diluted 1 to 10, or use—

(2) *Farmer's solution*, viz. :—

Hyposulphite of Soda	15 grms.
Ferricyanide of Potassium . . .	1 grm.
Water	100 c.c.

This gives an even reduction all over the plate. Or—

(3) *Persulphate reducer*, viz. :—

Persulphate of Ammonia . . .	2 grms.
Water	100 c.c.

This latter reducer acts first on the denser parts and leaves the half-tones unaffected, and is for this reason

to be preferred to the others when selective action is desired. It softens a hard negative. Rock the dish and examine the plate every half-minute. Wash immediately the reduction is sufficient.

N.B.—Use the moment the bath is made up, as it does not keep.

Stop the action as soon as the image viewed by transmitted daylight is clear enough. Then, if necessary, re-intensify a little to bring up the colours.

After intensification, clean in neutral permanganate bath (same as reversal bath for Lumière plate, only no acid is added). Then fix in hypo.

13. Instructions for Developing Omnicolore Plates. (Makers' Formulæ.)

Quantities suitable for $7\frac{1}{2} \times 5$ to whole plate size.

Solutions.	Duration.	Remarks.
A.—1st *Developer*, 13° C. to 18° C.— Water distilled, 100 c.c. ($3\frac{1}{2}$ oz.) Metol, 0·4 gm. (6 grs.) Hydroquinone, 0·2 gm. (3 grs.) Sodium Sulphite (anhyd.) 5 gms. (77 grs.) Carbonate of Potassium (dried) 3 gms. (46 grs.) Bromide of Potassium, 0·1 gm. ($1\frac{1}{2}$ grs.) Sodium Hyposulphite (1 % sol.), 1·5 c.c. (25 m.)	2 to 5 minutes	Wash for 20 seconds in the dark.

Solutions.	Duration.	Remarks.
B.—*Reversal Bath*— Distilled Water, 100 c.c. (3½ oz.) Bichromate of Potash or Soda, 0·8 gm. (12½ grs.) Sulphuric Acid, 1·2 c.c. (20 m.)	2 minutes	Wash for 2 minutes in the light.
C.—*Redeveloper*—Use 1st developer (A) or make up fresh developer		Leave plate in solution in bright daylight until it is quite black. Usually 4 minutes will suffice.
D.—*Fixing Bath*— Water (tap) 100 c.c. Hyposulphite of soda (crystal) 20 gms. Bisulphite of soda (or metabisulphite) 3 gms. (46 grs.)	Not to exceed 2 minutes	This bath is optional, but many workers consider the colours are more permanent and the positive is less liable to change if it is used.

NOTE.—Any one of Lumière's formulæ (Tables 7, 8 or 9) may be used for developing Omnicolore or Dufay plates, and the Omnicolore formulæ may be used for Autochrome plates. After the plate has been in the reversal bath for half a minute, it should be repeatedly examined in artificial light so as to stop the moment all details are visible, otherwise the high lights may be eaten away.

The plate must be thoroughly washed for 2 minutes after reversal to get all the bichromate out. It is advisable to put the plate for one minute in a 1 % solution of sodium bisulphite after washing. Then place in the old developing-bath and redevelop in bright daylight. If the plate is veiled or grey, place in a little of the old reversing solution, diluted 1 to 100 with water

for 20 seconds or so. Then wash and leave to dry. If the colours are not bright enough, intensify and, after washing, fix in hypo and again wash thoroughly. If the image is not intensified, the hypo bath may be omitted.

14. Instructions for Developing the Dufay Plate.

The instructions given for the Omnicolore plate will answer perfectly for the Dufay. Or Lumière's improved Quinomet developer will answer equally, but it is recommended to use the acid bichromate reverser instead of the permanganate, as it has greater penetrating power—although the latter may be used quite successfully.

The instructions given with the Dufay plate are as follows :—

A. *Developer*

Metol	6 grms.
Sulphite of Soda crystallised . .	75 ,,
Hydroquinone	2 ,,
Bromide of Potassium	2 ,,
Ammonia, ·880	12 c.c.
Water	1000 ,,

For use dilute with equal parts of water.

For a correctly exposed plate, develop for 4 to 5 minutes.

As soon as all the details have shown up, wash for 20 seconds and place in—

B. *Reversal Bath*

Bichromate of Soda or Potash . .	5 grms.
Sulphuric Acid	10 c.c.
Water	1000 ,,

The moment the plate is covered by this solution, take the dish and negative into daylight, and hold up the plate for a moment from time to time and examine by transmitted light, until the image appears quite distinct in its natural colours. Then wash under the tap immediately. If this is delayed too long the highlights will be eaten away. The usual time for this bath is 2 minutes.

Then wash for a minute or two and place in a 10 % sulphite of soda bath. If the air or water is too warm (*i.e.* over 68°), place the plate in a solution of chrome alum for a minute or two. Then redevelop in bright daylight in the first bath (A) until the plate is quite black.

For intensification, soak first in a saturated solution of perchloride of mercury for 5 minutes, or until quite bleached through.

Perchloride of Mercury (Sublimate)	40 grms.
Alcohol (Meth. Spirit)	200 ,,
Water	800 c.c.

Then into a 10 % solution of sulphite of soda in water.

These two baths can be repeated if desired, and may be used over and over again.

For under-exposure the density may be reduced by Farmer's solution (see Table 12), or the Persulphite reducer, or the reversal bath diluted 1 : 10 or 1 : 15 may be used, if the Hypo bath be objected to.

15. Instructions for Developing Paget Plates.

Development.

After exposure the Panchromatic Plate should be taken from the dark slide and developed in the ordinary way. The Taking Screen will, of course, be kept for future exposures.

Most developers may be used, provided the resulting negative be clean and soft. The best results are obtained with Rodinal, 1 in 30, and development should be complete in two minutes.

Unless a Green Safelight is used development must take place in total darkness. On no account should a Red Light or one of any colour other than the Safe Green be used. Development in total darkness presents no difficulty, as if the exposure given is about right, the time of development with Rodinal as given above will be correct.

Rinse the plate and fix in the following bath:—

Hypo	6 ozs.
Potass. Metabisulphite	½ oz.
Water	20 ozs.

Wash again for about 15 minutes, and put to dry.

Making the Transparency.

From the negative made in accordance with the foregoing instructions a contact transparency is made, and to obtain the best results the following conditions must be observed.

The Transparency should be of black tone, perfectly

clear, and free from fog, brilliant and full of detail. These conditions can be secured by using the special transparency plates issued in connection with this process, and adhering to the instructions therewith.

Registration.

When the Transparency is dry it is ready to be registered with the Viewing Screen. The method of doing this is to place the Transparency upon the Viewing Screen, film to film, and holding them up together in this position so as to look through. Keeping one of the plates stationary, move the other about slowly, maintaining contact all the time, and altering the position by minute steps, until all signs of any pattern have disappeared, when a slight movement either to the right or left will show the picture in its correct colours. Clip the plates together with strong letter clips and bind in the same way as with ordinary lantern plates.

16. Elimination of Green Spots.

Mr. J. McIntosh recommends that the green spots should be cut out with a sharp knife, and then a lantern plate exposed in contact with it. The exposure must be very brief. On development, a grey spot will be seen corresponding in position and size to the hole. After fixing and drying it the spot can be retouched and worked up with Aniline colours to harmonise with the picture. The negative must then be bound up with the positive film to film.

17. Recent Devices for Protecting the Colour Slide from the Heat Rays of the Lantern.

M. Massiot protects the slide by separating the two halves of the condenser by means of a freely ventilated wooden box, which is placed outside the lantern. It measures about 8″ or 10″ long. In order to further diminish the heat, the to and fro carrier is provided with two converging lenses of a focus selected to suit the objective. These lenses being thrown outside the path of the rays with each change of slide, have time to cool, and thus become only moderately heated. It must be explained that each lens attached to the carrier really forms part of the condensing system, and its addition is necessary to completely fill the slide with light. Zeiss in his Epidiascope projecting lantern has quite overcome the difficulty by employing a mirror which reflects the light through the transparency at such a distance from the source as to render it perfectly safe from injury. It is now sold in Paris under the name of the "Frigida" projecting lantern. It is, moreover, a very much cheaper form of lantern than the Zeiss model. A somewhat similar device is fitted to the projecting lantern sold by the firm of Bouch and Lomb, which may be obtained from Staley and Co., 24, Thavies Inn, London.

18. Sensitising and Resensitising Colour Plates.

Dr. König, in a recent number of the "Photogr. Rundschau," has strongly recommended the following sensitising bath :—

Alcohol	100 c.c.
Pina chrome-violet (1 : 1000).	3 c.c.
Orthochrome, Pinaverdol, or Pinachrome (1 : 1000) .	3 c.c.
Water (distilled)	200 c.c.

Bathe for three minutes; do not wash.

The doctor points out the immense superiority of these dyes over pinachrome behind a red filter, and over a mixture of pinacyanol and orthochrome when exposing behind a green filter.

19. Colour-screen Filters and Monochromatic Light.

The Mercury vapour spectrum yields the following lines:—

Yellow . . .	Wave-length		579 $\mu\mu$ and 576 $\mu\mu$
Green . . .	,,	,,	546 $\mu\mu$
Blue	,,	,,	436 $\mu\mu$
Violet. . . .	,,	,,	407 $\mu\mu$ and 405 $\mu\mu$

Red is entirely absent.

The three following filters will be found useful with this lamp:—

To transmit yellow light only of $\lambda = 579\ \mu\mu$ and $576\ \mu\mu$

Potas. bichrom.	15 grms.
Copper sulphate	3·5 grms.
Sulphuric acid	1 c.c.
Distilled water	300 c.c.

To transmit green light, of $\lambda = 546\ \mu\mu$

Picric acid	0·4 grm.
Copper sulphate	3·5 grm.
Didymium nitrate	15 grms.
Water.	300 c.c.

To transmit blue light only of $\lambda = 407\ \mu\mu$ and $405\ \mu\mu$

Copper sulphate	1 grm.
Distilled water	225 c.c.
Ammonia (0·880)	75 c.c.

20. A. B. Hitchins' Developer.

Owing to his vast experience in colour portraiture this formula can be recommended with every confidence:—

Metol	6·5 grms.
Sod. sulphite	40 ,,
Hydroquinone	2·1 ,,
Pot. bromide	2·5 ,,
Sod. hyposulphite . . .	0·1 gram.
Ammonia (0·880) . . .	20 c.c.
Water	1000 ,,

Carry on development until the high lights and flesh tones just begin to show reversal and transparency when viewed against the green Virida safelight, *i.e.* in about 3 to 4 minutes. Rinse in water and then place in reverser. This is best made up as follows:—

Potas. bichrom.	4 grms.
Sulphuric acid	15 c.c.
Water	1000 ,,

Then redevelop with—

Sod. sulphite (anhydrous) . . .	21 grms.
Diamidophenol	6 grms.
Pot. bromide (10% solution) . .	100 minims.
Water	1000 c.c.

Continue development for 4 minutes. Temperature of water 65 F.

N.B.—If a very clear transparent positive be desired,

or for lantern exhibition, add to first developer 4·7 grms. of Ferrocyanide of Potassium (*not Ferri-cyanide*), and omit the Hypo.

21. Metric Equivalent Tables.

Solid measures (Metric).			Solid measures (British).	
1 Milligram	$=\frac{1}{65}$ grain		1 grain	=65 milligrams
1 Centigram	$=\frac{1}{6 \cdot 5}=0 \cdot 154$ grain		2 ,,	=13 centigrams
1 Decigram	=1·543 grains		3 ,,	=19·5 ,,
0·1 Gramme	=1·5 ,,		4 ,,	=26 ,,
0·2 ,,	=3 ,,		5 ,,	=32·4 ,,
0·3 ,,	=4½ ,,		6 ,,	=39 ,,
0·4 ,,	=6 ,,		7 ,,	=45 ,,
0·5 ,,	=7½ ,,		8 ,,	=52 ,,
0·6 ,,	=9 ,,		9 ,,	=58 ,,
0·7 ,,	=11 ,,		10 ,,	=65 ,,
0·8 ,,	=12½ ,,		11 ,,	=72 ,,
0·9 ,,	=14 ,,		12 ,,	=78 ,,
1 ,,	=15·43 ,,		13 ,,	=84·5 ,,
2 ,,	=31 ,,		14 ,,	=91 ,,
3 ,,	=46 ,,		15 ,,	=97·4 ,,
4 ,,	=62 ,,		16 ,,	=1·04 grammes
5 ,,	=77 ,,		17 ,,	=1·1 ,,
6 ,,	=92·5 ,,		18 ,,	=1·17 ,,
7 ,,	=108 ,,		19 ,,	=1·23 ,,
8 ,,	=123 ,,		20 ,,	=1·3 ,,
9 ,,	=139 ,,		30 ,,	=1·95 ,,
10 ,,	=154 ,,		40 ,,	=2·6 ,,
14 ,,	=216=½ oz. avoir.		50 ,,	=3·24 ,,
20 ,,	=308 grains		60 ,,	=3·9 ,,
28 ,,	=437 grains=1 oz. av.		¼ oz. avoir.	=7 ,,
			½ ,, ,,	=14·17 ,,
			1 ,, ,,	=28·35 ,,
			1 lb.=16 oz.	=454 ,,

Note.—Gramme is generally written "gr.," but English writers usually indicate it by gm. or grm., to distinguish it from gr. (grain), but the occurrence of c.c. in the one case, or ounces and minims in the other case, will enable the reader to know at once which measure "gr." stands for. On the Continent all liquids as well as solids are sold by weight in grammes.

Fluid measures (Metric).	Fluid measures (British).
1 c.c. = 17 minims (m.)	1 minim (m.) = $\frac{1}{17}$ c.c. = 0·06 c.c.
2 ,, = 34 ,,	5 ,, = 0·29 ,,
3 ,, = 51 ,,	10 ,, = 0·59 ,,
3·5 ,, = 60 = ʒi (1 drachm)	20 ,, = 1·18 ,,
4 ,, = 68 minims	30 ,, = 1·77 ,,
5 ,, = 85 ,,	40 ,, = 2·36 ,,
6 ,, = 1 dr. 41 m.	50 ,, = 2·95 ,,
7 ,, = 2 ,,	1 drachm (ʒi) = 3·5 ,,
8 ,, = 2 ,, 15 ,,	2 ,, = 7 ,,
9 ,, = 2½ ,,	2½ ,, = 9 ,,
10 ,, = 2 ,, 49 ,,	3 ,, = 10·65 c.c.
11 ,, = 3 ,, 6 ,,	4 ,, (½ fl.oz) = 14 ,,
12 ,, = 3 ,, 23 ,,	5 ,, = 17·5 ,,
13 ,, = 3 ,, 40 ,,	6 ,, = 21·3 ,,
14 ,, = 4 ,,	7 ,, = 24·7 ,,
15 ,, = 4 ,, 14 ,,	1 fl. oz. (℥i) = 28 ,,
20 ,, = 5 ,, 8 ,,	2 ,, (℥ii) = 57 ,,
25 ,, = 7 ,,	3 ,, (℥iii) = 85 ,,
28 ,, = ℥i (1 fl. oz.) = 480 m.	3½ ,, (℥iiiss) = 100 ,,
30 ,, = 8½ dr.	4 ,, (℥iv) = 113 ,,
40 ,, = 1 fl. oz. 2 drms.)	1 pint (Oi) = 568 ,,
50 ,, = ℥i ʒvi (1 fl.oz. 6 dr.)	35·2 fl. oz. = 1000 c.c. = 1 litre
75 ,, = ℥ii ʒv	1 quart = 1·136 litres
100 ,, = ℥iiis (3½ fl. oz.)	1 gallon = 4·546 litres
1000 ,, = 1 litre = 35·2 fl. oz.	

Conversion of grammes per litre into grains per ounce: multiply the grammes by 0·44, product is grains per ounce. For c.c. per litre into minims per ounce, multiply by 0·48. Conversion of grains per ounce into grammes per litre: multiply grains by 2·3, product is grammes per litre. Thus 40 grs. in 16 ozs. = 2½ grs. per oz., and 2·5 × 2·3 = 5·75 grammes per litre. For minims per ounce into c.c. per litre, multiply the number of minims by 2·3. Thus 20 mm. in 4 ozs. = 5 m. per ounce, and 5 × 2·3 = 11·5 grammes per litre.

Measures of Length (Metric).

1 Kilometre = 1000 M. = 1094 yards = $\frac{5}{8}$ mile.
1 Metre (M.) = 10 decimetres = 100 cm. = 39·37 in.
1 Decimetre (dm.) = 10 cm. = 3·937 in.
1 Centimetre (cm.) = 10 mm. = 0·3937 in.
1 Millimetre (mm.) = 1000 microns = $\frac{1}{25}$ in. = 0·03937 in.
1 Micron (μ) = 1000 micromillimetres = $\frac{1}{25000}$ in.
1 Micromillimetre ($\mu\mu$) = 10 Angstrom units (often written A.U.) = $\frac{1}{1000000}$ mm. = $\frac{1}{25000000}$ in.

Measures of Length (British).

1 mile = 1609 M.	1 foot = 30·47 cm.
1 furlong = 201 M.	1 inch = 25·4 mm.
1 yard = 91·41 cm.	1 line = 2 mm.

Inches to millimetres.

Inches		mm.		cm.
$\frac{1}{16}$	=	1·58	=	0·16
$\frac{1}{8}$	=	3·17	=	0·32
$\frac{1}{4}$	=	6·35	=	0·63
$\frac{3}{8}$	=	9·5	=	0·95
$\frac{1}{2}$	=	12·7	=	1·27
$\frac{5}{8}$	=	15·9	=	1·59
$\frac{3}{4}$	=	19	=	1·9
$\frac{7}{8}$	=	22·2	=	2·2
1	=	25·4	=	2·54
2	=	50·8	=	5·08
3	=	76·2	=	7·6
4	=	101·6	=	10·1
5	=	127	=	12·7
6	=	152	=	15·2
7	=	177	=	17·7
8	=	203	=	20·3
9	=	229	=	22·9
10	=	254	=	25·4
11	=	280	=	28
12	=	304	=	30·4
13	=	330	=	33
14	=	355	=	35·5
15	=	381	=	38·1
16	=	406	=	40·6
17	=	431	=	43·1
18	=	458	=	45·8
19	=	483	=	48·3
20	=	508	=	50·8

The above values are correct to $\frac{1}{2}$ mm.

Centimetres to inches.

cm.		inches.
1	=	$\frac{3}{8}$
2	=	$\frac{13}{16}$
3	=	$1\frac{3}{16}$
4	=	$1\frac{9}{16}$
5	=	$1\frac{31}{32}$
6	=	$2\frac{3}{8}$
7	=	$2\frac{3}{4}$
8	=	$3\frac{5}{32}$
9	=	$3\frac{9}{16}$
10	=	$3\frac{15}{16}$
11	=	$4\frac{5}{16}$
12	=	$4\frac{11}{16}$
13	=	$5\frac{1}{8}$
14	=	$5\frac{1}{2}$
15	=	$5\frac{15}{16}$
16	=	$6\frac{5}{16}$
17	=	$6\frac{11}{16}$
18	=	$7\frac{1}{16}$
19	=	$7\frac{1}{2}$
20	=	$7\frac{7}{8}$
21	=	$8\frac{1}{4}$
22	=	$8\frac{5}{8}$
23	=	9
24	=	$9\frac{3}{8}$
25	=	$9\frac{7}{8}$
26	=	$10\frac{1}{4}$
27	=	$10\frac{5}{8}$
28	=	11

The above values are correct to $\frac{1}{32}$ in.

22. English and Foreign Sizes of Plates.

Continental Sizes of Plates.

Centimetres.	Inches.	Centimetres.	Inches.
4·5 × 6·0	$1\frac{3}{4}$ × $2\frac{3}{8}$	13 × 21	5·12 × 8·25
9 × 12	3·54 × 4·72	18 × 24	5·12 × 8·25
12 × 16	4·72 × 6·30	24 × 30	9·44 × 11·80
13 × 18	5·12 × 7·08	30 × 40	11·80 × 15·75

English Sizes of Plates.

Inches.	Centimetres.	Inches.	Centimetres.
$3\frac{1}{2}$ × $2\frac{1}{2}$	8·9 × 6·4	7 × 5	17·8 × 12·7
$3\frac{1}{4}$ × $3\frac{1}{4}$	8·25 × 8·25	$8\frac{1}{2}$ × $6\frac{1}{2}$	21·5 × 16·5
$4\frac{1}{4}$ × $3\frac{1}{4}$	10·8 × 8·25	10 × 8	25·4 × 20·3
5 × 4	12·6 × 10·1	12 × 10	30·4 × 25·4
$6\frac{1}{2}$ × $4\frac{3}{4}$	16·5 × 12·0	15 × 12	38·1 × 30·4

23. Comparative Plate Speeds.

H. and D.	Watkins.	Wynne.
1	$1\frac{1}{2}$	8
2	3	11
3	4,5	14
4	6	16
5	$7\frac{1}{2}$	18
8	12	22
10	15	24

N.B.—Hurter and Driffield's 2, Watkin's 3, and Wynne's Meter 11 correspond to Wellcome's Plate Speed No. 12, which is the correct number for Autochrome and Dufay plates out of doors.

The makers give for Autochrome Plates Watkin's 3 and Wynne 11 and for Paget Plates (separate), Watkin's $7\frac{1}{2}$ and Wynne 18. In both cases with filter in position.

24. Wave Lengths of Visible Spectrum.

			768$\mu\mu$	Visible limit of spectrum
Wave length of dark red	A	line	= 759	Oxygen line
,, ,, deep red	a	,,	= 733	Water vapour
,, ,, red	B	,,	= 687	Oxygen ,,
,, ,, light red	—	,,	= 670	Lithium ,,
,, ,, orange red	C	,,	= 656	Hydrogen vapour
,, ,, yellow	D	,,	= 589	Sodium ,,
,, ,, green	E	,,	= 527	Iron ,,
,, ,, bluish-green	b	,,	= 518	Magnesium ,,
,, ,, greenish-blue	F	,,	= 486	Hydrogen ,,
,, ,, blue	—	,,	= 460	Lithium ,,
,, ,, blue-violet	G	,,	= 434	Iron ,,
,, ,, violet	H	,,	= 397	Visible limit of spectrum Calcium vapour
	K	,,	= 393	Ultra-violet begins

Roughly speaking, blue extends from 400 to 500, green and yellow from 500 to 600, red from 600 to 700 $\mu\mu$.

25. Thermometric Scales

Centigrade, (Celsius) C.	Fahrenheit F.	Réaumur R.	Centigrade C.	Fahrenheit F.	Réaumur R.
0°	32°	0°	26	78,8	20,8
1	33,8	0,8	27	80,6	21,6
2	35,6	1,6	28	82,4	22,4
3	37,4	2,4	29	84,2	23,2
4	39,2	3,2	30	86,0	24,0
5	41,0	4,0	31	87,8	24,8
6	42,8	4,8	32	89,6	25,6
7	44,6	5,6	33	91,4	26,4
8	46,4	6,4	34	93,2	27,2
9	48,2	7,2	35	95,0	28,0
10	50,0	8,0	36	96,8	28,8
11	51,8	8,8	37	98,6	29,6
12	53,6	9,6	38	100,4	30,4
13	55,4	10,4	39	102,2	31,2
14	57,2	11,2	40	104	32
15	59,0	12,0	45	113	36
16	60,8	12,8	50	122	40
17	62,6	13,6	55	131	44
18	64,4	14,4	60	140	48
19	66,2	15,2	65	149	52
20	68,0	16,0	70	158	56
21	69,8	16,8	75	167	60
22	71,6	17,6	80	176	64
23	73,4	18,4	85	185	68
24	75,2	19,2	90	194	72
25	77,0	20,0	95	203	76
			100°	212°	80°

Rule.—To convert—

C° into F°. Multiply C° by 9, divide by 5, and add 32.
R° into F°. Multiply R° by 9, divide by 4, and add 32.
C° into R°. Multiply C° by 4, and divide by 5.
R° into C°. Multiply R° by 5, and divide by 4.
F° into C°. Subtract 32 from F°, multiply remainder by 5, and divide by 9.
F° into R°. Subtract 32 from F°, multiply remainder by 4, and divide by 9.

Note.—Fahrenheit's scale is only used in English-speaking countries. Réaumur's scale is used by the general public in most countries on the Continent. The Centigrade scale is now used in all countries by physicists and chemists, and this scale is therefore implied in scientific works unless otherwise specially mentioned.

26. LIST OF ALL THE FIRMS MENTIONED IN THIS WORK, together with their Postal Addresses and Telephone Numbers. (Lens and Camera Makers are omitted.)

Name of Firm.	Postal Address.	Telegraphic Address and Telephone No.
Actien Ges. für Analin fabrikation.	Berlin.	
Autotype Co.. .	74, New Oxford St., W.C.	Central, 873
Baker, Charles .	244, High Holborn.	
Bayer & Co. . .	Elberfeld, Germany.	
Berger v. Wirth .	Benthstrasse, Berlin.	
Böhringer . .	Mannheim, Germany.	
Burroughs Wellcome & Co.	Snow-hill Buildings, Holborn Viaduct, E.C.	Central, 13300.
Butler, H. T. .	26, Craven Park, Willesden, London, N.W.	
Dufay . . .	22,RueChateaudun,Paris. London Agents, Autotype Co. (*q.v.*)	
Fuerst Bros. . .	17, Philpot Lane, E.C.	Fuerst, London. LondonWall,4350.
T. K. Grant (successor to Lumière Co.	89, Great Russell St., London, W.C.	Diamido, London. Gerrard, 3419.
Grübler, Chemiker.	63, Baierische Strasse, Leipzig.	
Ives Inventions, Ltd.	939, Eighth Avenue, New York.	
Johnson & Sons .	Mfg. Chemists, Ltd., 23, Cross St., E.C.	London Wall, 677.
Jougla, J. & Cie.	45, Rue de Rivoli, Paris	T. N., 105–75.
Koenig, Dr. E.	See Fuerst Bros.	
Lumière,A.&Sons	Monplaisir, Lyon, France	Lumière, Lyon. T. N., 11–19.
Lumière A.& Sons	89,Great Russell St.,W.C.	Diamido, London. Gerrard, 3419.

Name of Firm.	Postal Address.	Telegraphic Address and Telephone No.
Dr. G. Mundie .	Mik. Chem. Institut, Göttingen, Hanover.	
Natural Colour Kinematograph Co., Ltd.	Wardour St., W.	Kinmacolor, London. T. N., City, 3976.
Paget Prize Plate Co., Ltd.	Watford, England, and 244, High Holborn, London, W.	
Raydex Co., Ltd.	71, Lavender Hill, S.E.	
Rotary Photo Co., Ltd.	12, New Union St., E.C.	Rotatoria,London. Wall, 1109.
Royal Photographic Society	35, Russell Square, W.C.	Central, 4124.
Sanger-Shepherd & Co.	5, Gray's Inn Passage, W.C.	Sentido, London. Central, 8722.
Smith, Dr. J. H. & Co.	Wollishofen, Zurich	Dryplate, Zurich. T. N., 484.
Urban. See Natural Colour Kinematograph Company, Ltd.		
Utocolor. Société Anonyme Utocolor.	La Garenne-Colombes, Paris.	
Watkins Meter Co.	Imperial Mills, Hereford	Watkins,Hereford.
Wratten & Wainwright	Croydon, Surrey	Wratten, Croydon. Croydon, 572.

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